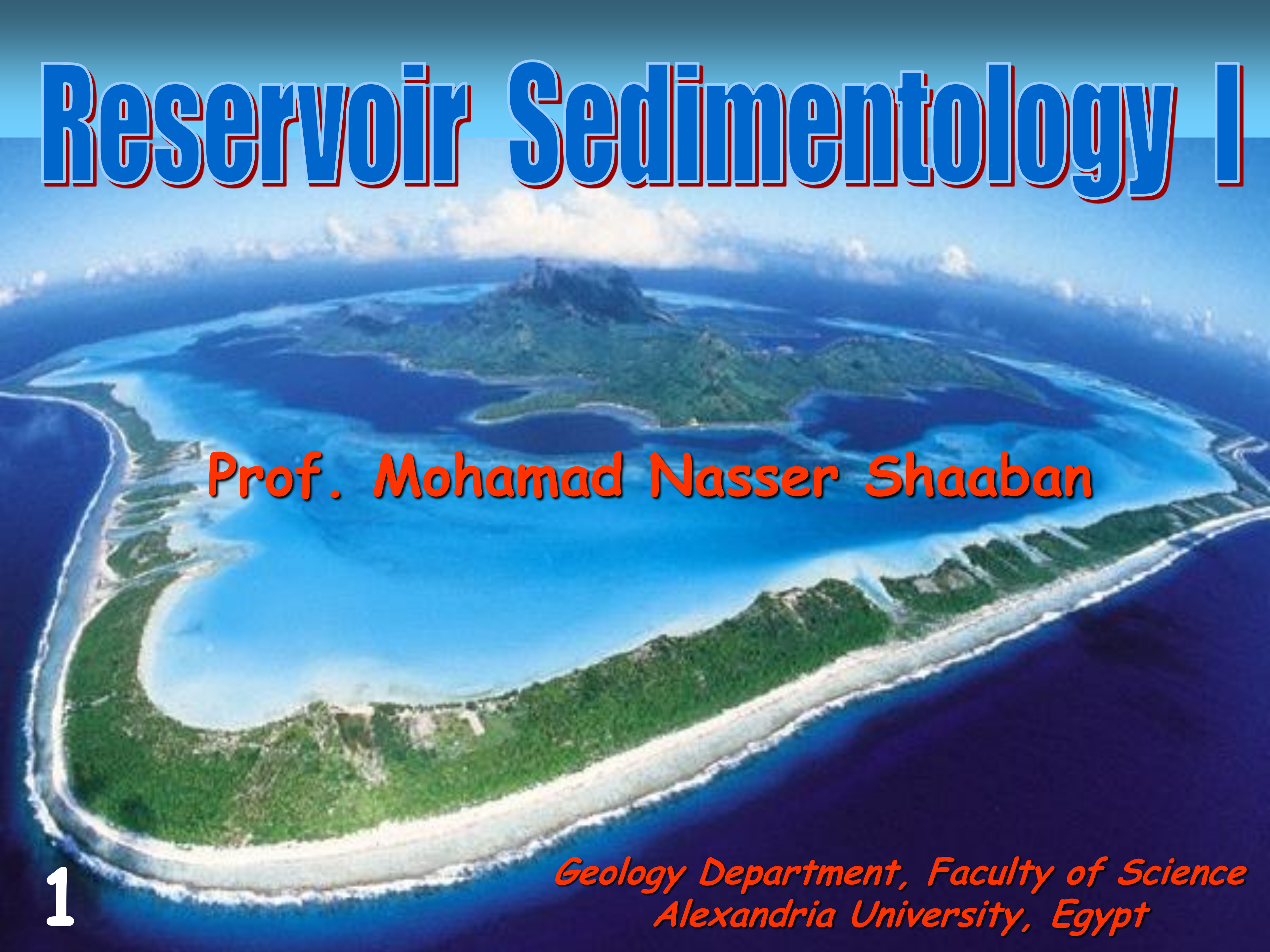
"قالوا سبحانك لا علم لنا إلا ما علمتنا"

Vision and Mission

- The program aims to provide a high-quality education in petroleum geology and to produce professional graduates for successful, social, and ethical responsible careers in the petroleum industry and who are capable of confronting the needs and expectations of oil and gas industries and stakeholders.
- The APGP is dedicated to serve the regional and national demands for well prepared graduates who are highly valued by employers and the community, and who are qualified to pursue advanced degrees.



Reservoir Sedimentology I

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Reservoir Sedimentology

1. Clastic Reservoirs

Reservoir Sedimentology

What do you expect to learn from this course?

What do you expect to learn from this course?

Aim of the Course

- To explain the concept of clastic hydrocarbon reservoir characterization.
- To discuss the fundamental sedimentological processes that govern the spatial and temporal variability of the different clastic sedimentary rocks *(i.e. to study the nature, characters, fabric elements, depositional environments, modeling of clastic sedimentary rocks)* in order to have better insight into reservoir characteristics.
- To evaluate the parameters *(e.g. porosity and permeability)* that control reservoir quality and to discuss how these parameters vary spatially and with burial, due to depositional facies variability and diagenetic processes.
- To facilitate the professional development of the student.

What the course is about?

1. **Introduction and Definitions**
2. **Factors controlling the production of clastic sediments and sedimentary rocks**
   (Weathering, Erosion, Transportation, Deposition and depositional environments, Diagenesis)
3. **Clastic Reservoir Properties**
   - *Sedimentary structures and textures*
   - *The impact of clastic textures and fabrics on reservoir characterization*
   - *Petrographic types of clastic reservoir rocks*
   - *How clastic reservoir properties are affected by diagenesis?*
4. **Clastic Reservoir Development and Morphology**
   - *Clastic facies and facies analysis*
   - *Clastic depositional environments*
   - *The concept of sequence stratigraphy and how it is used in clastic reservoir characterization*

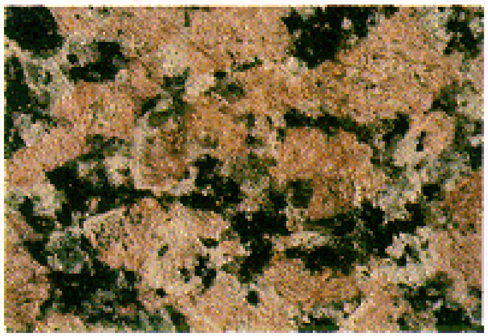
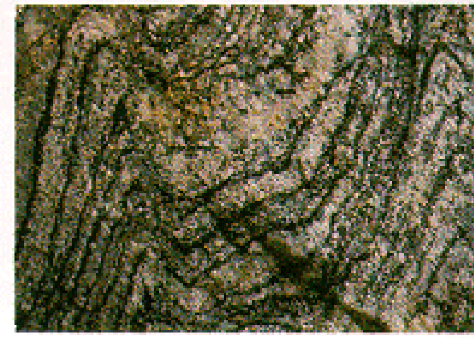
Introduction

What is Geology?

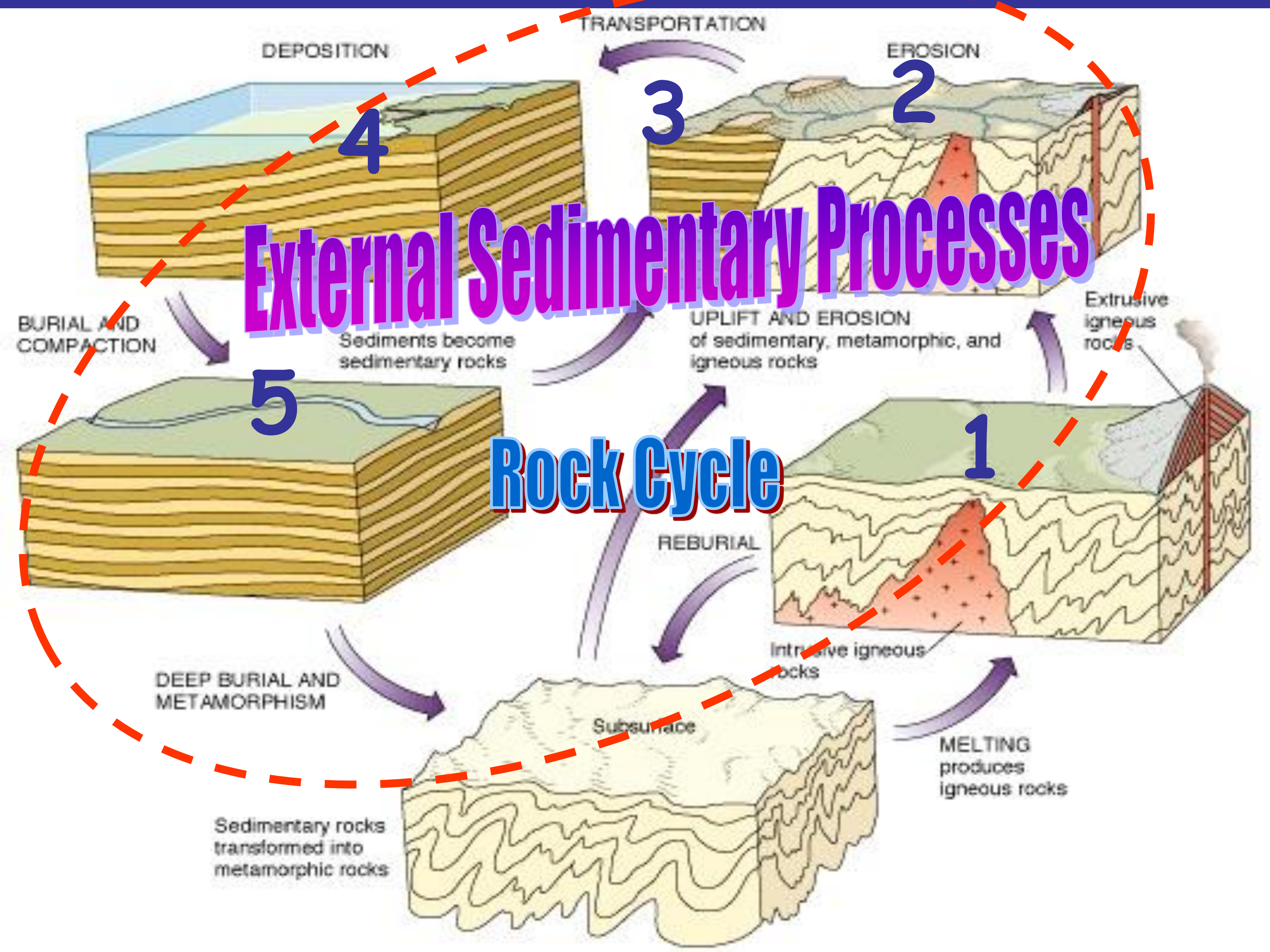
It is the branch of science that study everything about the earth on which we live; for instance:

- ✓The internal processes within the earth,
- ✓The external processes surrounding the earth and the interaction between the four spheres (litho, hydro, bio & atmosphere),
- ✓The earth's materials and natural resources

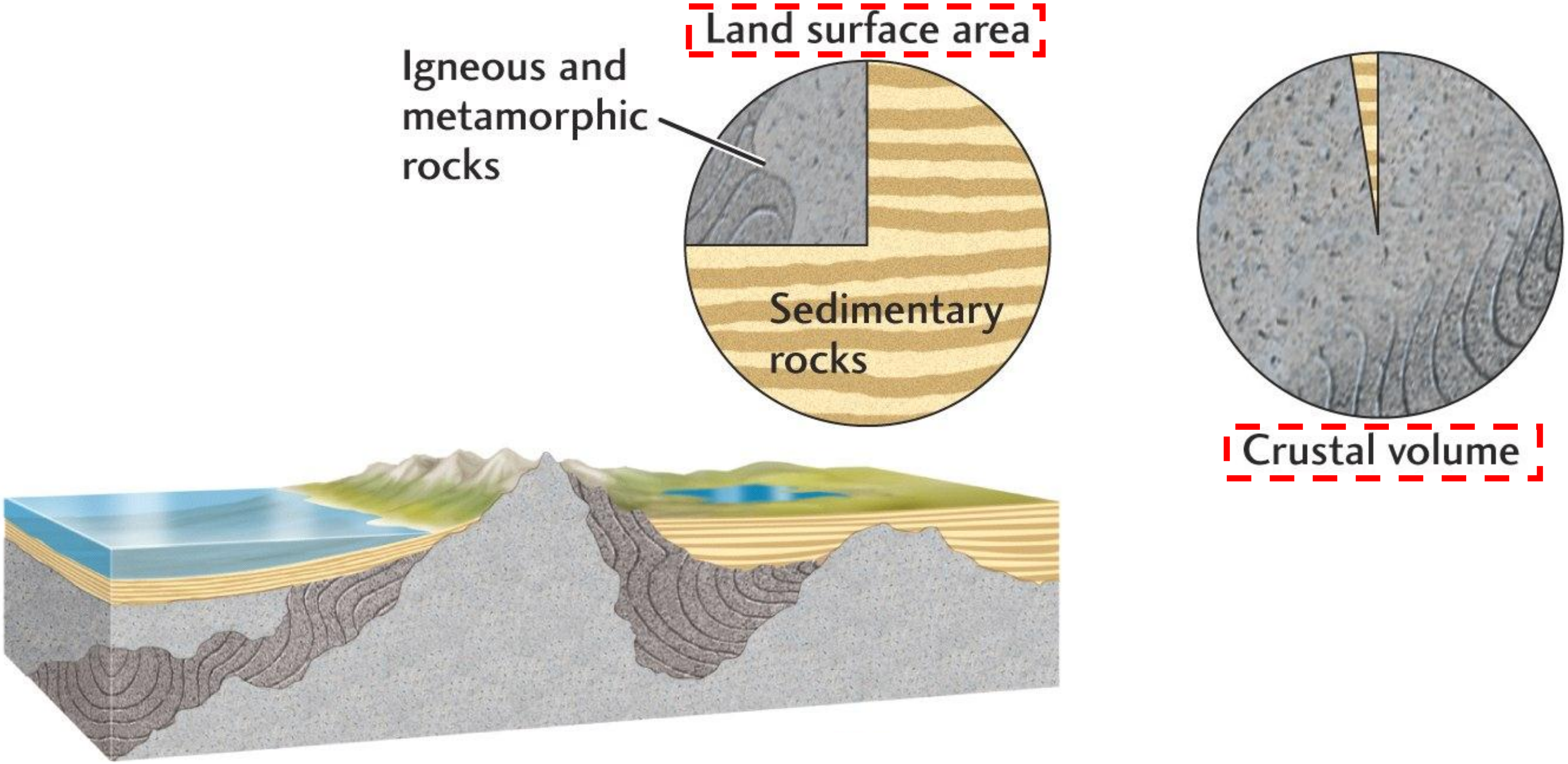
Before Starting You Have to know that there are three types of rocks that constitute the Earth's Lithosphere: their classification is based on their origin

	IGNEOUS	SEDIMENTARY	METAMORPHIC
			
Source of material	**Molten materials in deep crust and upper mantle**	**Weathering and erosion of rocks exposed at surface**	**Rocks under high temperatures and pressures in deep crust**
Rock-forming process	**Crystallization (Solidification of melt)**	**Sedimentation, burial and lithification**	**Recrystallization due to heat, pressure, or chemically active fluids**

Sedimentary rocks are the most important as related to hydrocarbon industry


External Sedimentary Processes
Rock Cycle
TRANSPORTATION
DEPOSITION
EROSION
1
2
3
4
5
BURIAL AND COMPACTION
Sediments become sedimentary rocks
UPLIFT AND EROSION of sedimentary, metamorphic, and igneous rocks
Extrusive igneous rocks
REBURIAL
Intrusive igneous rocks
DEEP BURIAL AND METAMORPHISM
Subsurface
MELTING produces igneous rocks
Sedimentary rocks transformed into metamorphic rocks

Proportions of Rock Types on the Earth



Igneous & metamorphic rocks = crystalline rocks

SEDIMENTOLOGY OF CLASTIC RESERVOIRS

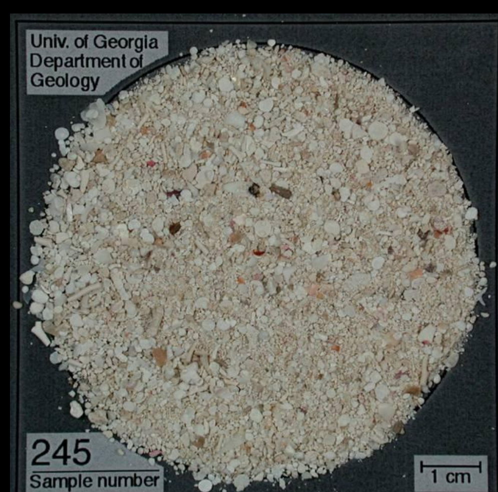
What is Sedimentology?

- It is the branch of science which deals with:
  1. *sediments*,
  2. *sedimentary deposits*
  3. *sedimentation processes*, *and*
  4. *sedimentary rocks*.


1. Sediments

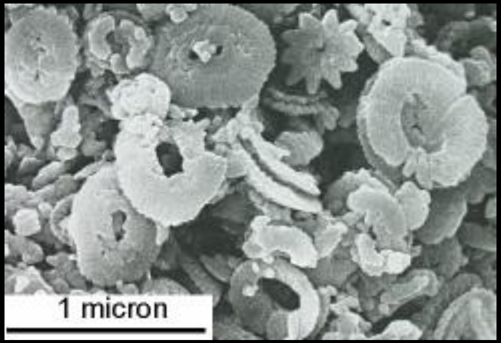
What are sediments?

- Sediments *are* Loose solid particles (grains)
- *derived from* the physical and chemical weathering of preexisting rocks
- *formed* at/ or near earth surface under low temperature and pressure .



Sediments may be either:

1. A fragment of a rock or mineral,
2. Crystals which precipitate directly from water,
3. Shells of marine organisms
4. Chemically or bio-chemically formed particles
5. Reef



2. Sedimentary Deposit

What is a sedimentary deposit?

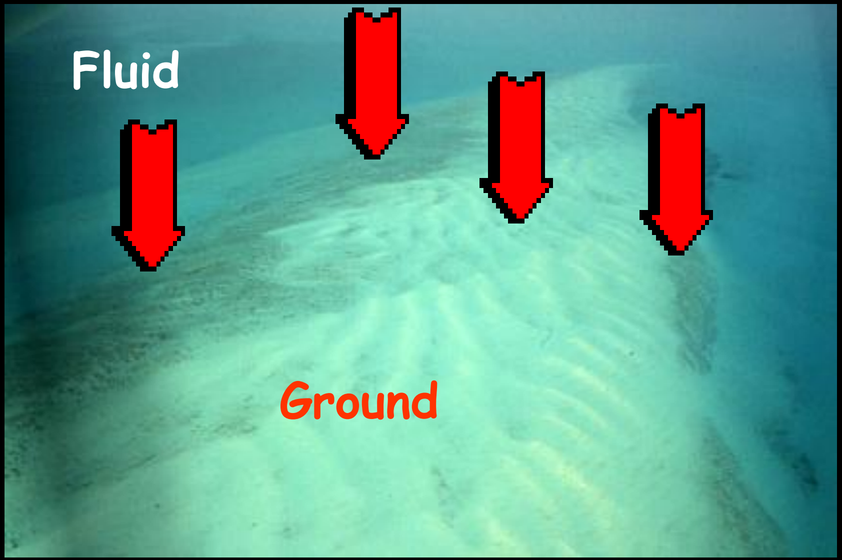
- It is a body of solid materials (sediments)
- accumulated at/or near surface of the earth
- within a specific sedimentary environment.

Is this a sedimentary deposit?


3. Sedimentation

What is sedimentation?

- It is the act of accumulation (falling down) of sediments onto a surface or ground under the influence of certain forces (e.g. gravity, turbidity currents,..)

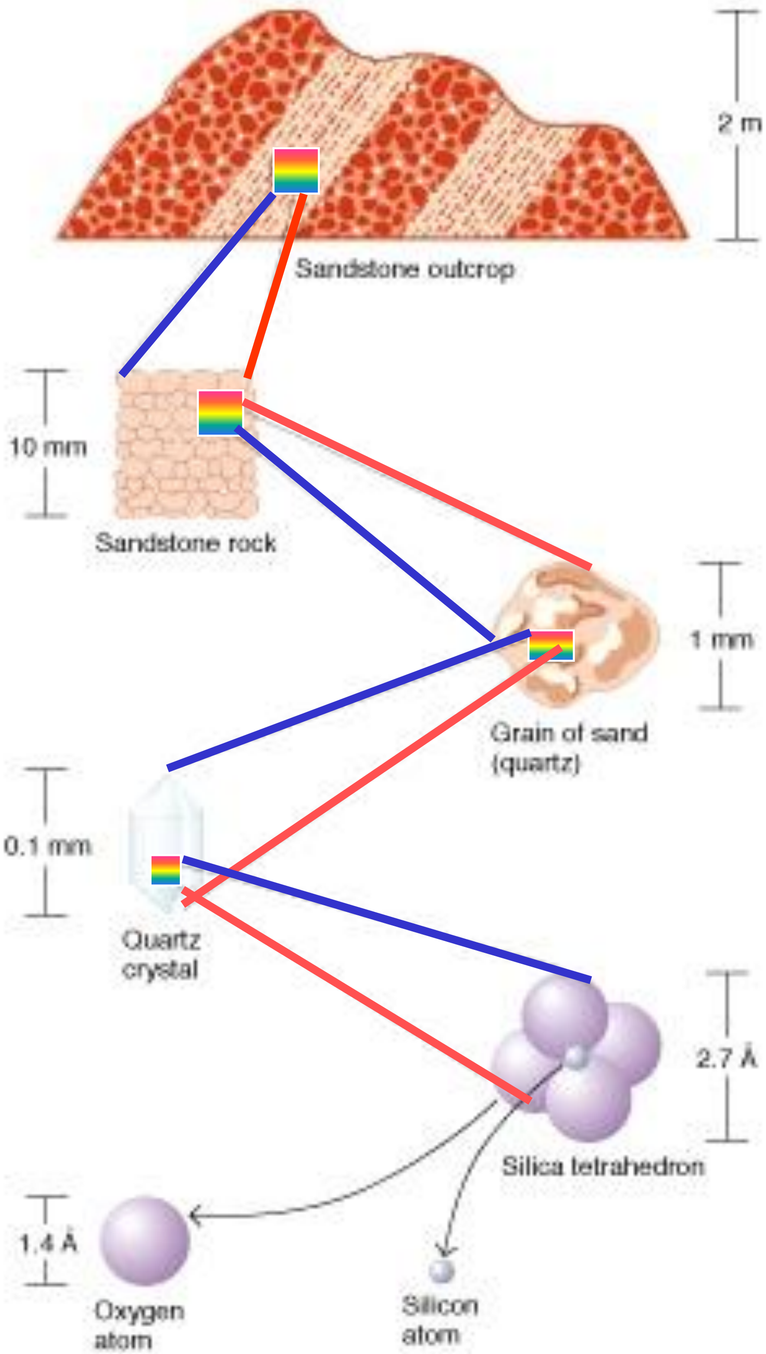


The formation of modern sand dunes is a kind of sedimentation

When sand dunes become consolidated with time, *a process called diagenesis or lithification*, they form "Sandstones"

4. Sedimentary Rock

Before we define a sedimentary rock we have first to revise back the principal meaning of a rock in its general sense



What is a Rock?

Minerals

Minerals are naturally formed, generally inorganic crystalline solid composed of an ordered array of atoms having a specific composition.

Elements

What are Sedimentary Rocks?

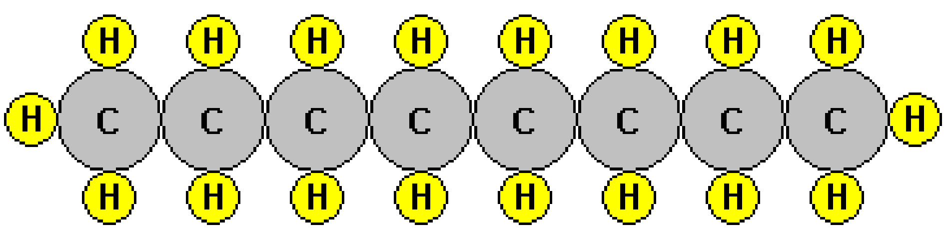
- Sedimentary rocks are defined as those rocks formed via the deposition and lithification (diagenesis) of loose sediments.
- Sedimentary rocks are secondary rocks (i.e. they are formed from pre-existing rocks)
- They form at or near the earth's surface at relatively low temperatures and pressures primarily *by either*:
  - a) *mechanical fragmentation & transport*
  - b) *precipitation from solution (may be biologically mediated); and /or*
  - c) *growth in position by organic processes (e.g., carbonate reefs)*

Sedimentary Rocks

What Sedimentary Rocks have to do with oil industry?

What is Petroleum?

- *Physically*, Petroleum is a natural, yellow-to-black, flammable, substance found beneath the earth's surface



- *Chemically*, Petroleum is an organic compound, liquid or gas, consisting of organic molecules *(composed of hydrogen and carbon atoms)*. Thus the general name "hydrocarbons" is often used.

The main forms of hydrocarbons (oil and gas)

Hydrocarbon: composed of H and C

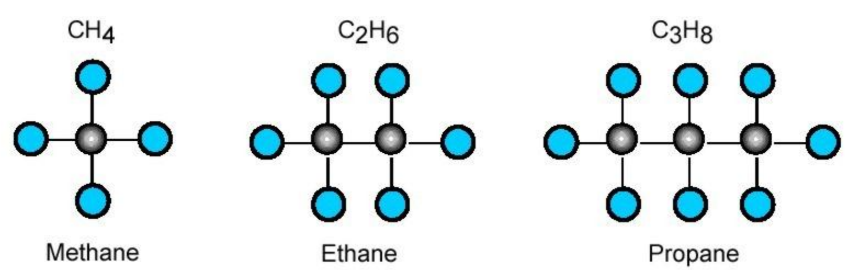
Gases

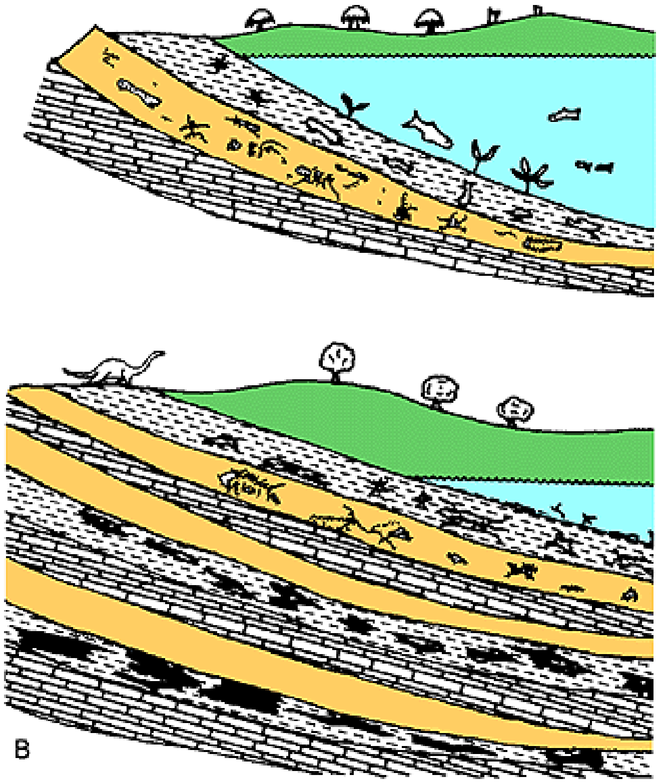
Liquid
Oil, Crude

Plastic
Asphalts
Kerogen

Dry
methane

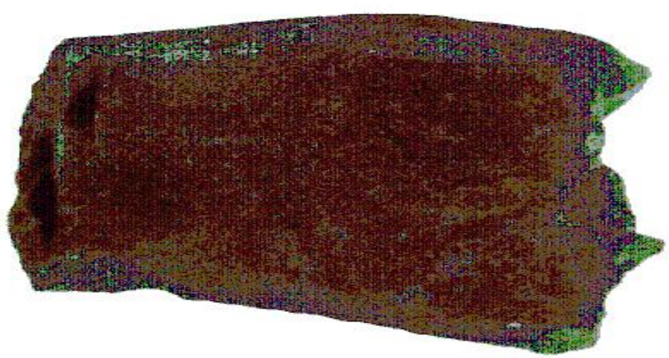
Wet
ethane,
propane

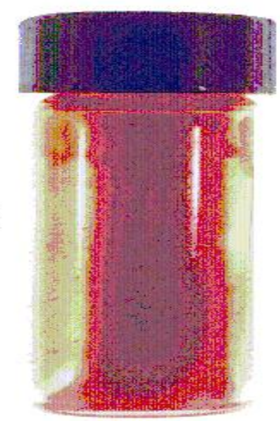




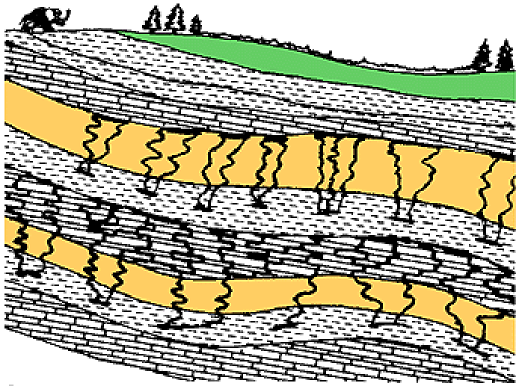
The Origin of Petroleum

- Life existing in an ancient sea hundreds of millions of years ago and burial of organic matter in the sediments
- Millions of years later the sediments have increased in thickness and the organic matter is being altered into petroleum under high temperature and pressure





Organic-rich Source Rock → Thermally Matured Organic Matter → Oil



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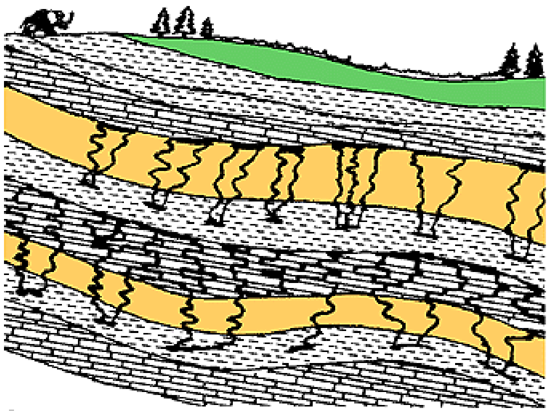

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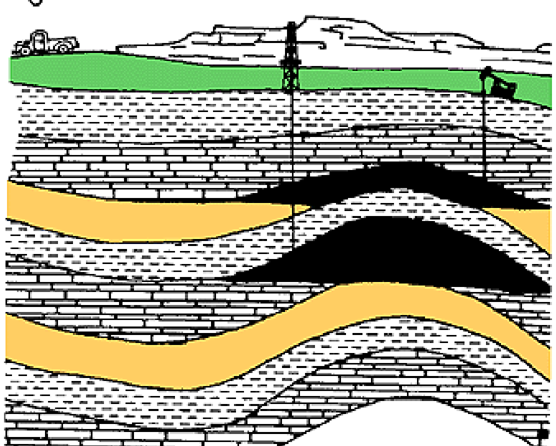


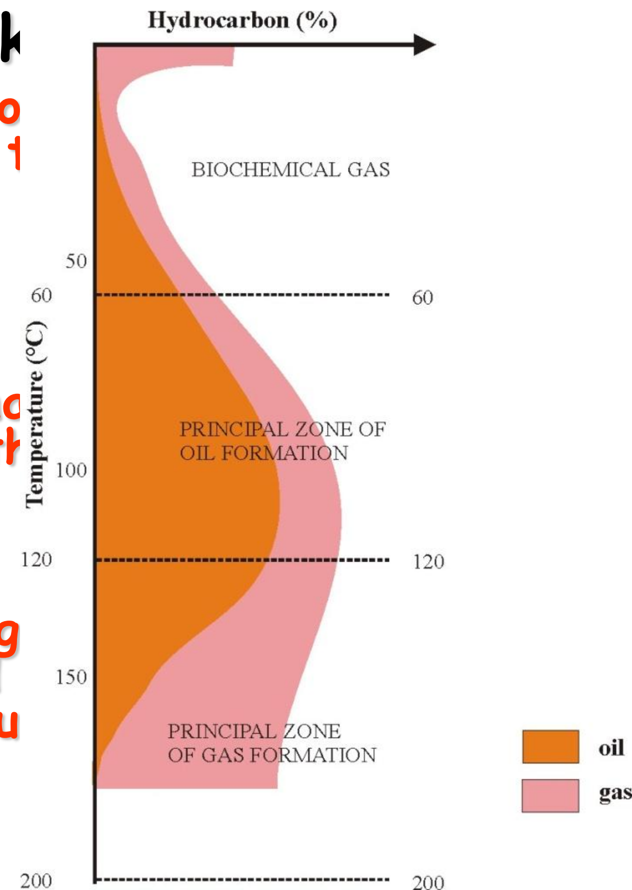
D

- Petroleum migrates from the source rocks into porous rocks (the reservoir rock).
- Tiny globules of oil or bubbles of natural gas collect at the top of the reservoir layer
- Such accumulations are usually too small to be recovered practically from a well.
- However, if the rocks are tilted somehow, the petroleum will continue to migrate up the sloping top of the bed until it reaches the surface or an impermeable barrier to its flow where the petroleum is trapped within a reservoir.

So, the formation of an oil accumulation requires:

1. Adequate organic source material.
   - most petroleum is derived from the accumulation of trillions of individual micro-organisms.
2. Burial to the appropriate depths.
   - depths of 2-6 km and temperatures of 60-160° C.
3. Presence of a reservoir-quality rock

   a porous storage space. Sandstone and limesto
   common reservoir rocks. To be a reservoir t
   - Porosity, to hold the hydrocarbons
   - Permeability, to allow fluid flow
4. Presence of an adequate seal
   - A seal is an impermeable bed (such as a sha that sits on top of the trap and prevents th rising any further.
5. Presence of a trap
   - In order to prevent the hydrocarbons rising escaping they must be caught in a confined trap. i.e. the source, reservoir and seal mu such a way that the petroleum is trapped.



In addition to the 5 components, further events are essential:

Timing: no trapping unless the traps are present when migration is occurring

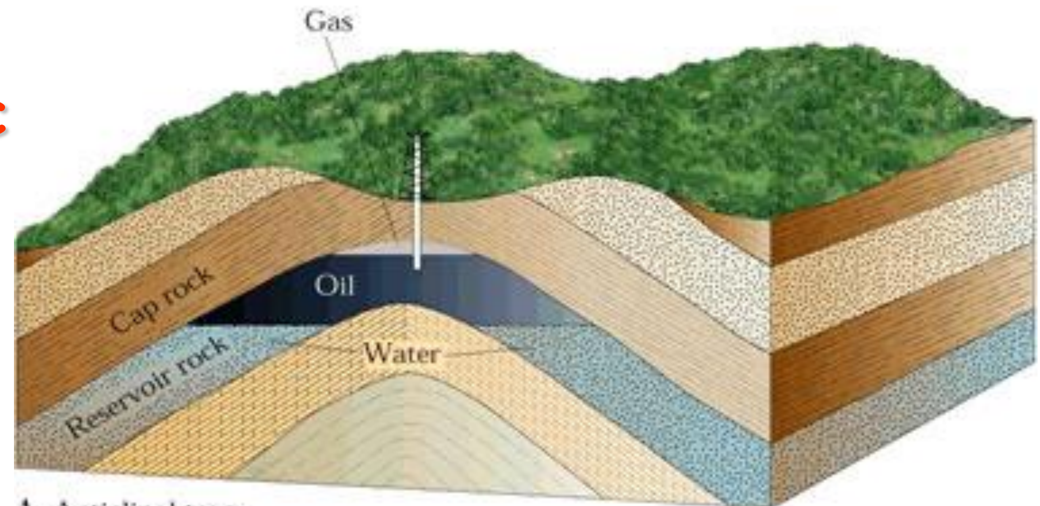
Maturation: no petroleum if the source rock Organic Matter does not mature

Migration: no accumulation if the petroleum doesn't migrate

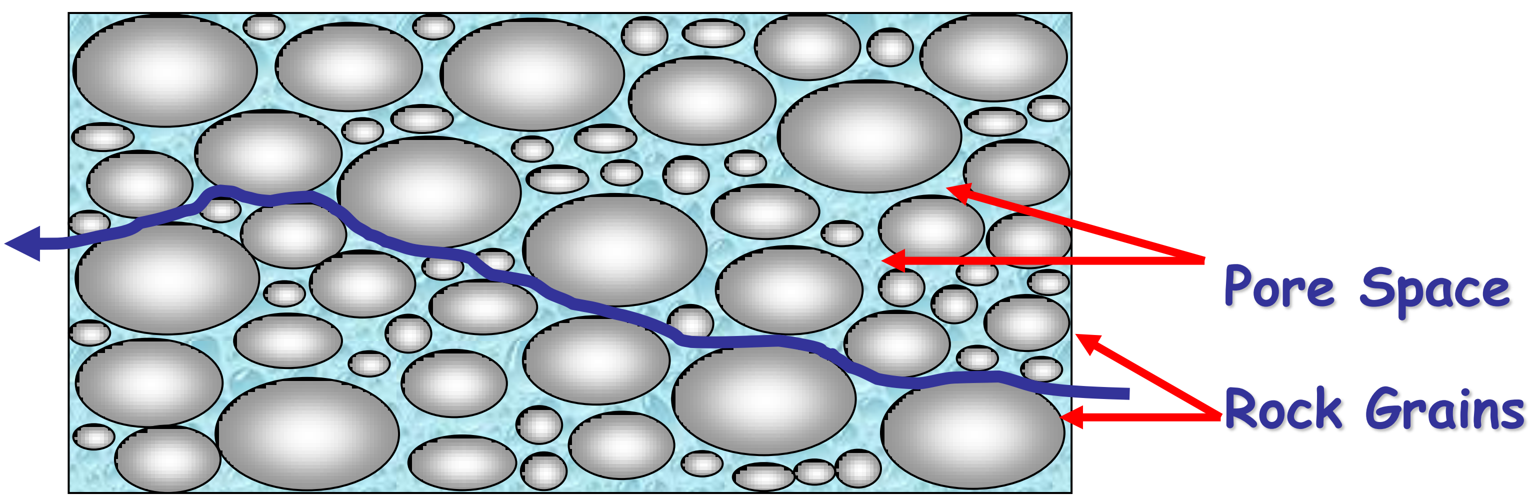
What is a Reservoir?

Poros_3.mpg

It is a rock *(mainly sedimentary rock)* characterized by specific petrophysical characters that allow hydrocarbons to be stored and move within it in the subsurface.



A. Anticlinal trap



What Sedimentary Rocks have to do with oil industry?

Hydrocarbons

Initiated from
a sedimentary rock
(e.g. Black shale)

Stored within
a sedimentary rock
(e.g. Sandstone)

Trapped and capped
by a sedimentary rock
(e.g. Evaporites)

How

1. Reservoir characteristics,
2. Oil exploration &
3. Production procedures

are

in critical dependence on sedimentological principles?

The Exploration and Production of Oil

The Exploration and Production of Oil

pass through three main stages

1. *First preliminary exploration phase*
2. *Subsequent establishment of drillable prospects*
3. *Final phase of development drilling and production*

Sedimentologic principles are involved, in a way or another in these three stages

1. First preliminary exploration phase

- Close link is necessary with geophysics to elucidate gross structure and stratigraphy.
- Seismic data can *detect sedimentary features related to reservoirs and oil trapping as delta fronts, reefs, salt diapirs*.

2. Subsequent establishment of drillable prospects

- This step is based primarily on *subsurface facies* analysis in order to evaluate *the nature and distribution of reservoirs*.

3. Final phase of development drilling and production

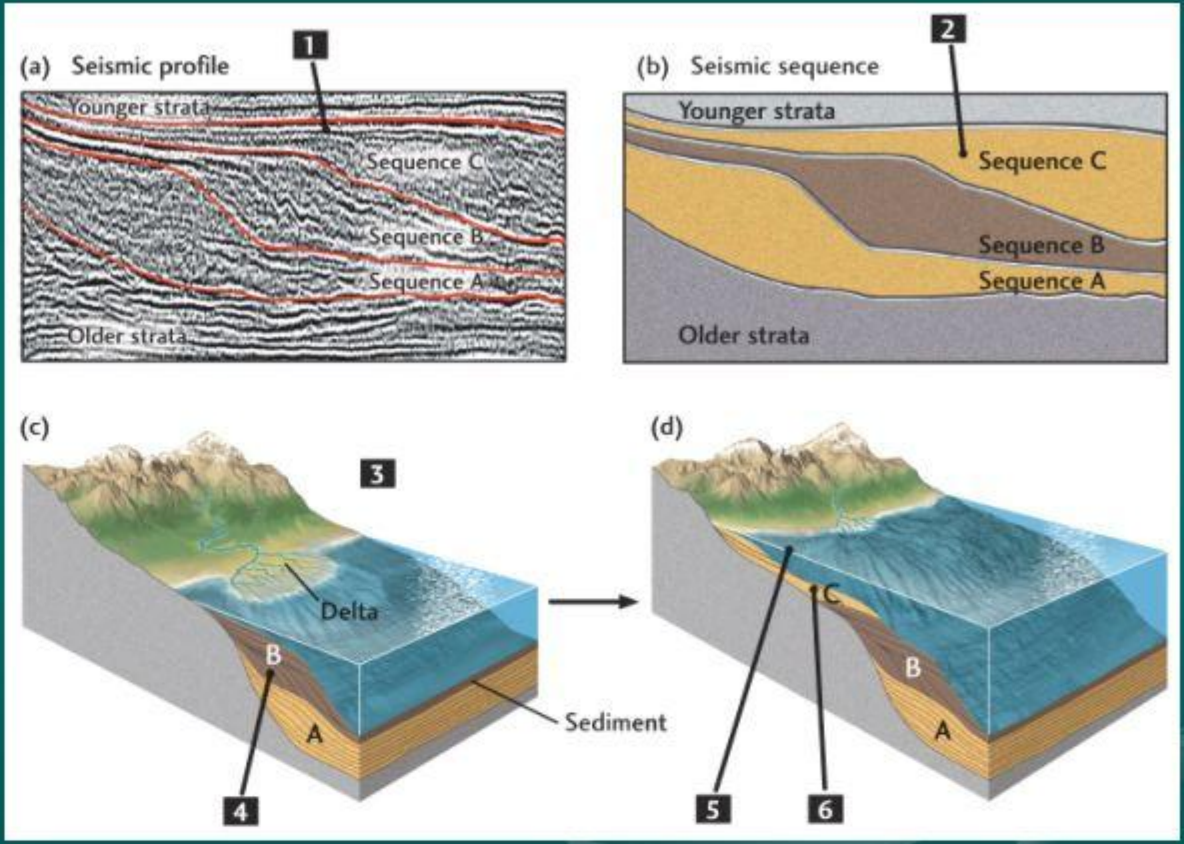
- This phase requires good information about *petrography and petrophysics of reservoir rocks* in order to predict well locations which will produce the maximum oil and the minimum amount of water.

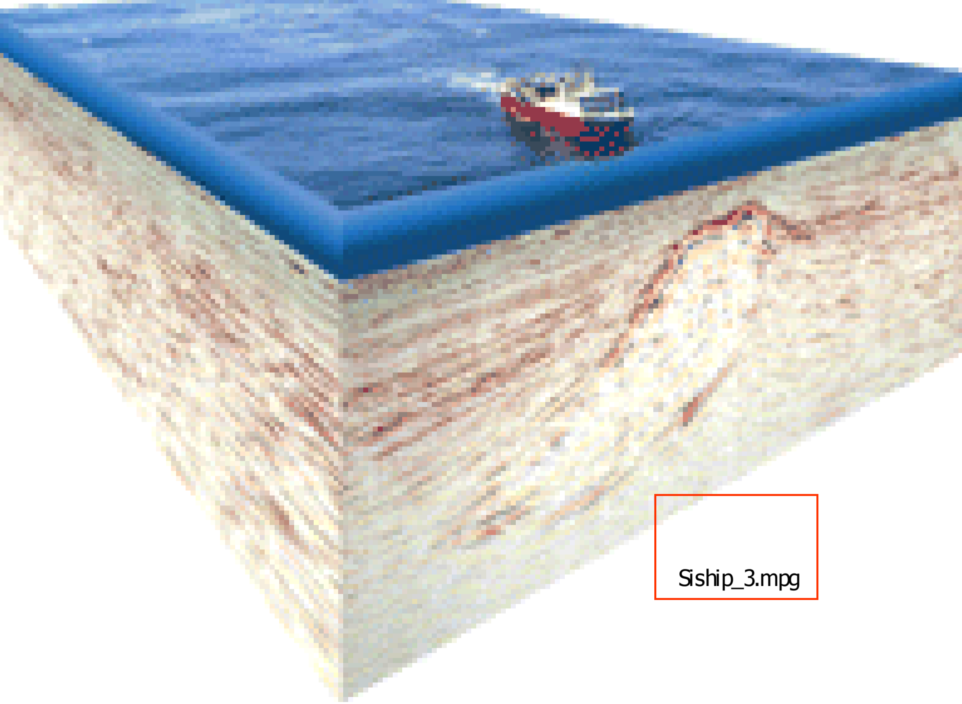
1. First preliminary exploration phase

1. First preliminary exploration phase

Close link is necessary with geophysics to elucidate gross structure and stratigraphy

Sequence stratigraphy





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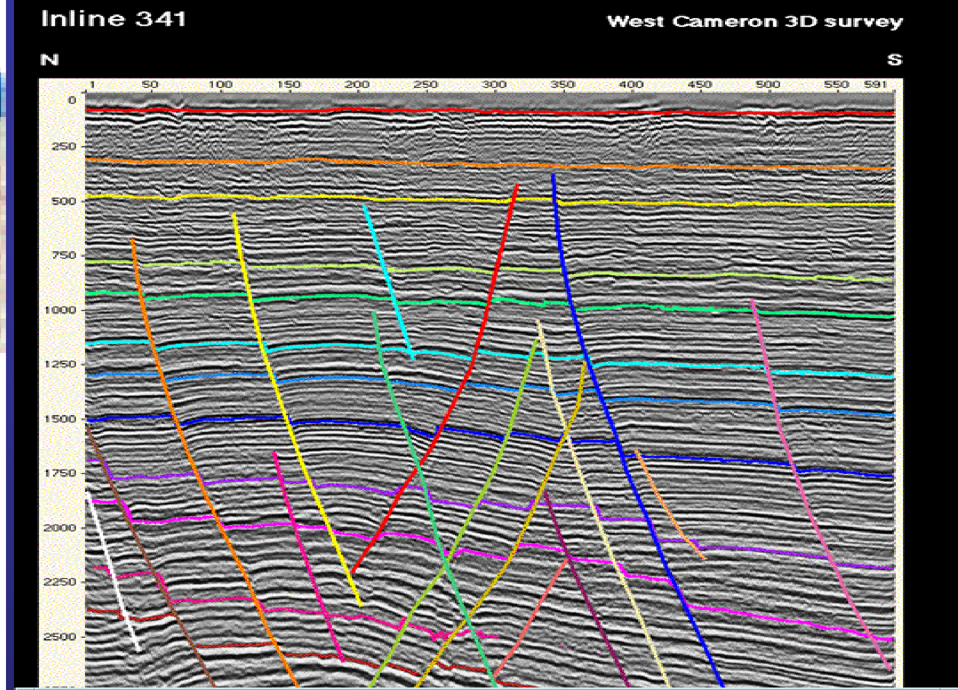

Inline 341
West Cameron 3D survey
N
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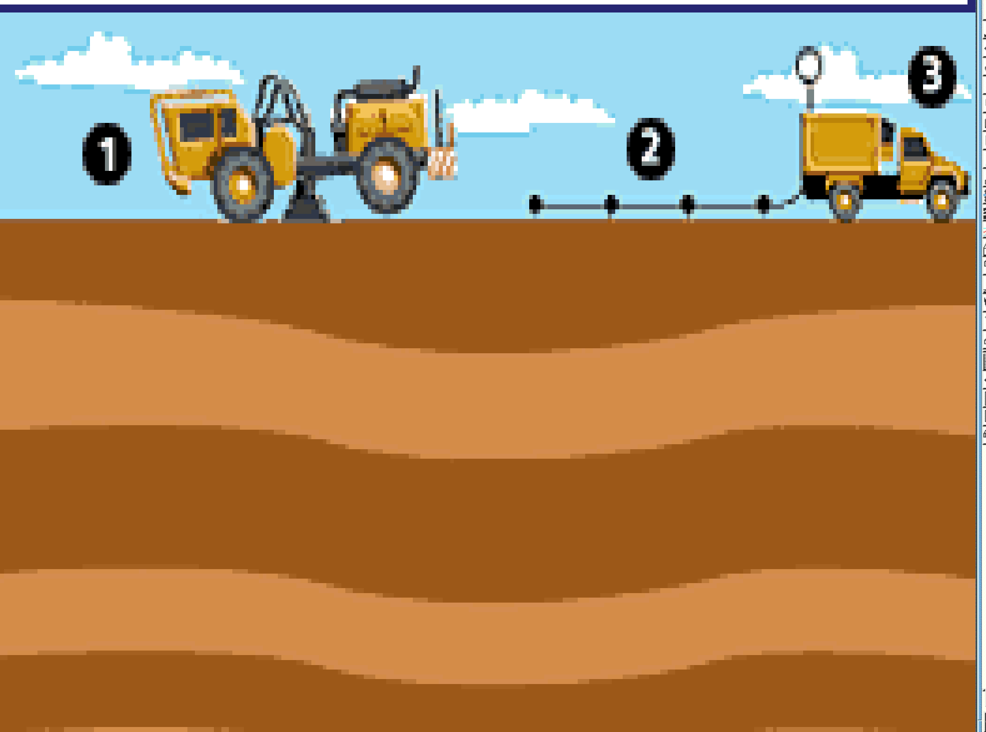

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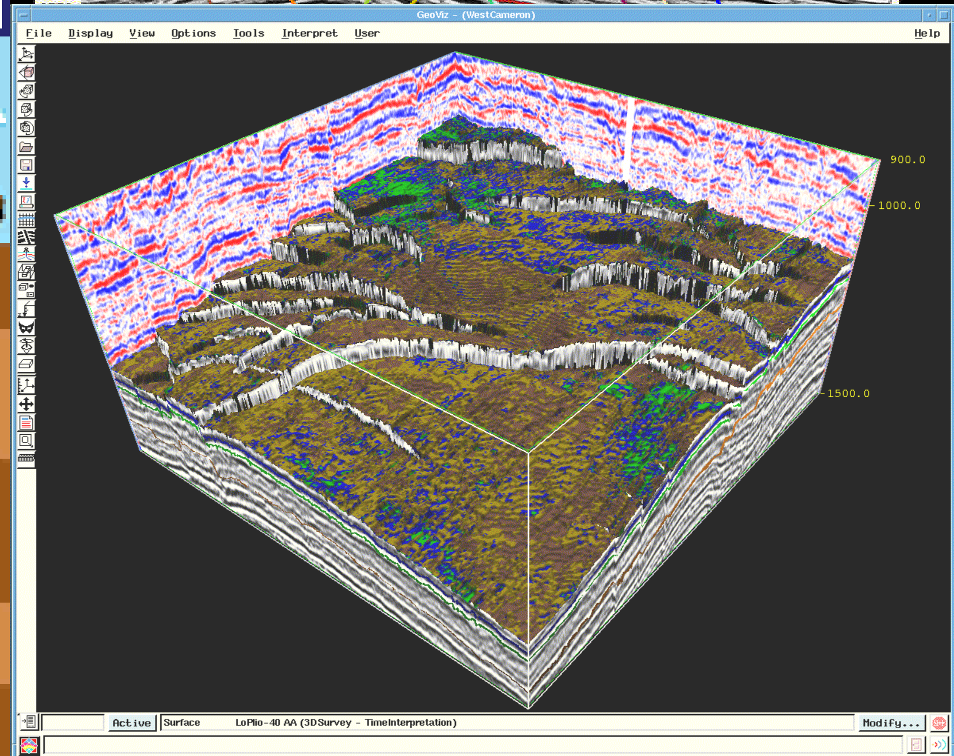

GeoViz - (WestCameron)
File Display View Options Tools Interpret User Help
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1000.0
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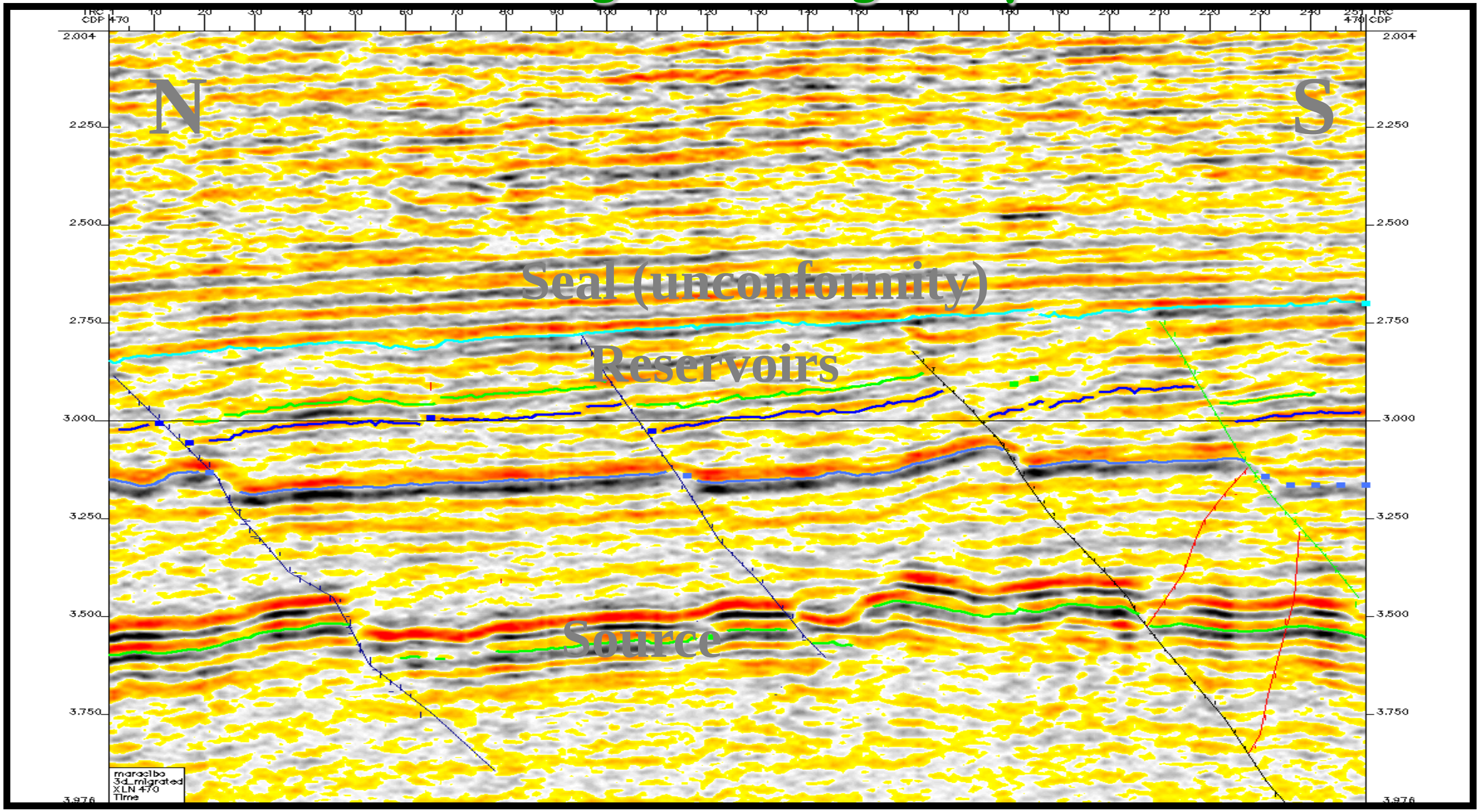
Active
Surface
LoPlio-40 AA (3DSurvey - TimeInterpretation)
Modify...

Pre-Drilling Knowledge Exploration



•Structural information obtained from surface seismic data (i.e. Make a structural model of the reservoir).

•Rough geological information can be provided by (Delineate and map reservoir-quality rocks)

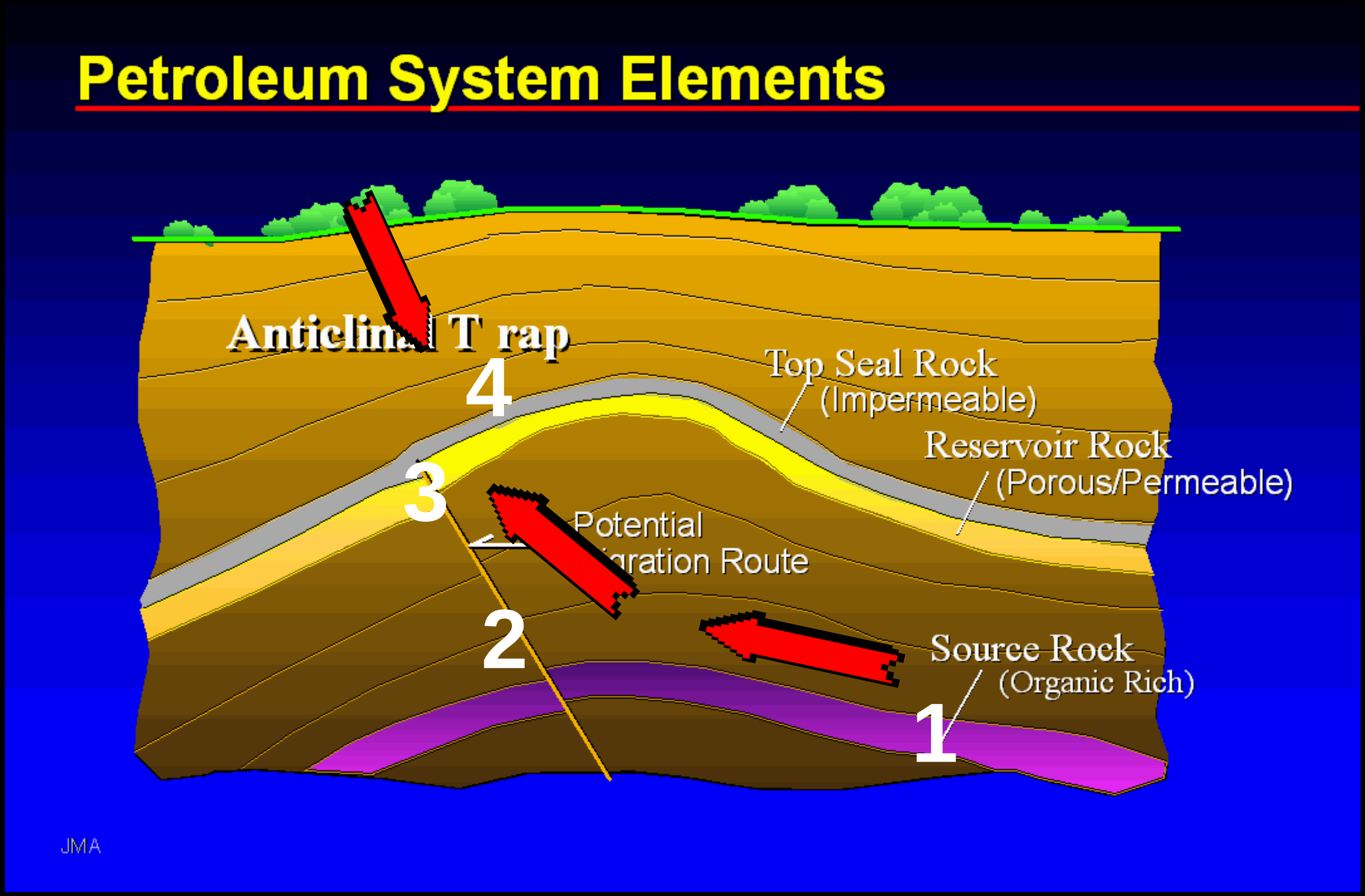
•Approximate depths estimated from surface seismic data (e.g. Establish gas/water contacts

2. Subsequent establishment of drillable prospects (i.e. defining a hydrocarbon play)

2. *Subsequent establishment of drillable prospects (i.e. defining a hydrocarbon play)*

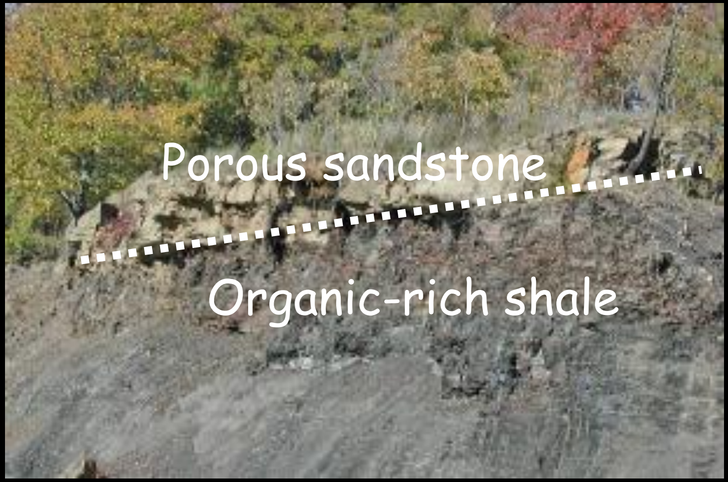
- A play is a group of features that have a high probability of containing oil or gas when found together. This is what a play looks like:

- This step is based primarily on *subsurface facies* analysis in order to evaluate *the nature and distribution of reservoirs*

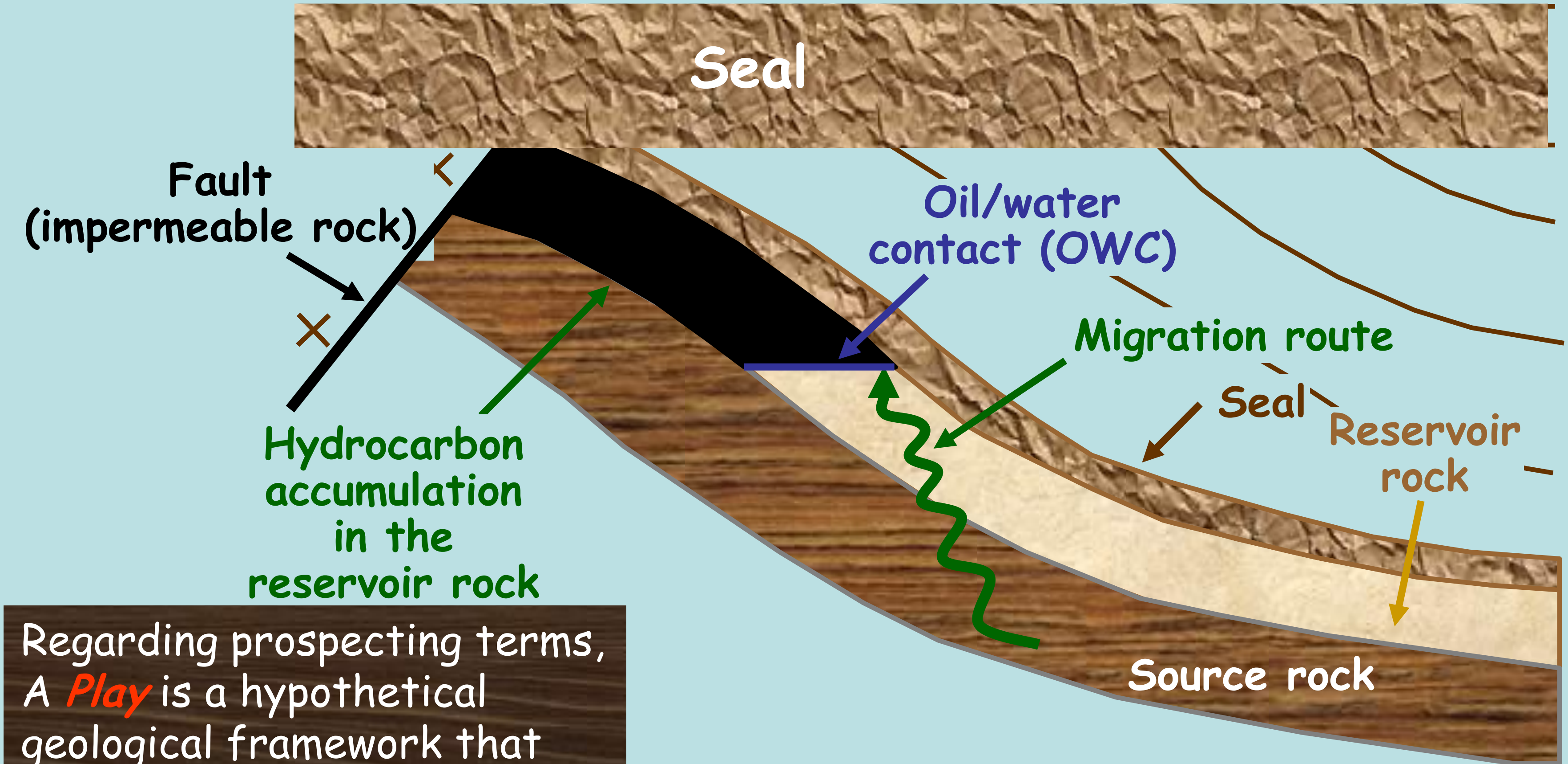


What Makes a Play?

- The first necessary feature is *source rock*, or rock that would contain petroleum.
- Since the creation of petroleum increases pressure the petroleum leaves source rock and moves upward.
- In order for petroleum to be extracted source rock must somehow be connected to a layer of porous rock which can absorb the oil and other byproducts (*reservoir rock*).
- Finally, this porous rock needs to be capped off by a layer of harder rock to keep it all in there (*Cap rock or a seal*).



Subsurface Tracing of Generation, Migration, and Trapping of Hydrocarbons: Facies Analysis of Hydrocarbon Play



Regarding prospecting terms, A *Play* is a hypothetical geological framework that contains all the elements necessary to find petroleum

Elements of a Play

The Source Rock

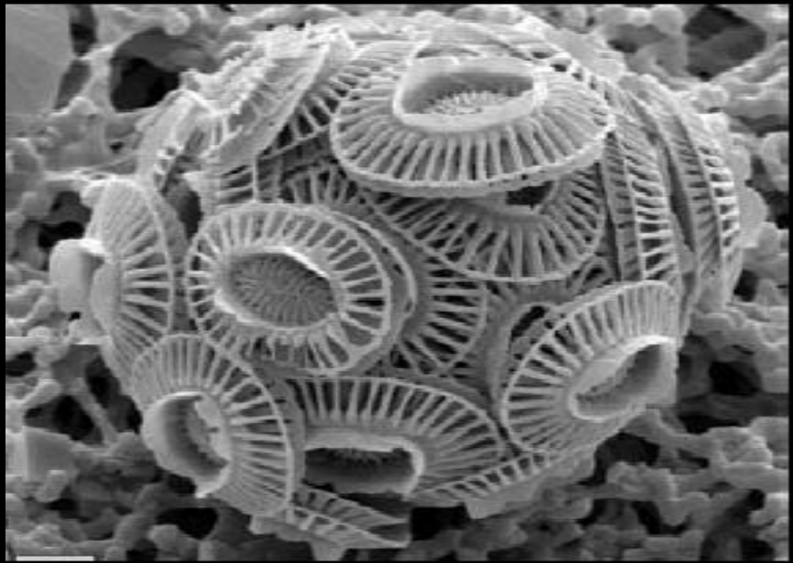
This shale typically contains >1% of organic carbon, by weight. Shale is by far the most important source rock for the oil that has been found in the North Sea Basin.

Black oil shale is the major Source rock: Generators of oil & gas

•Oil and gas are generated from rocks (mainly shales) rich in organic matter, derived primarily from **microscopic** plants and animals and larger land plants:

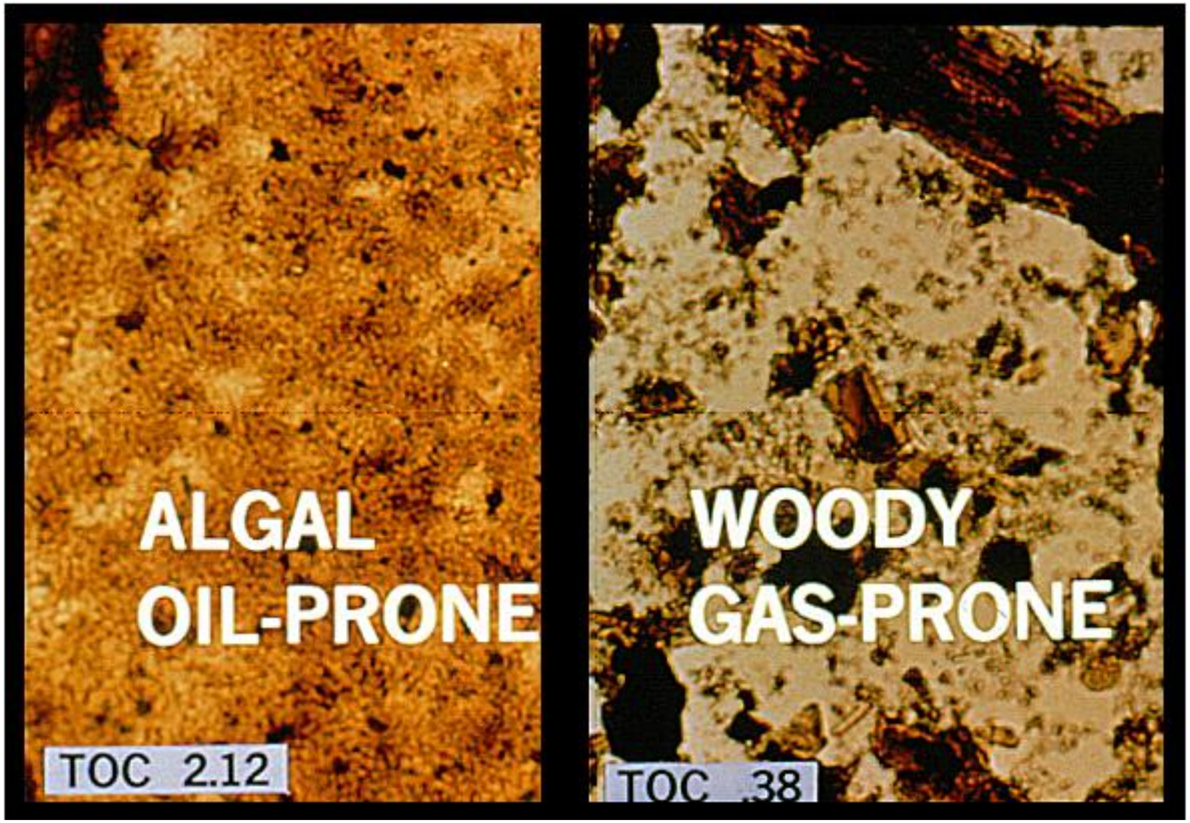
✓ *bacteria*
✓ *marine algae*
✓ *small marine invertebrates*
✓ *larger land plants*

Marine calcareous algae (oil-prone)



Land plants (gas-prone)

Kerogen Types



TOC 2.12 WT.%

TOC .38 WT.%

Algae = **Hydrogen rich = Oil-prone**

Wood = **Hydrogen poor = Gas-prone**

Source rocks

- With burial into the subsurface, i.e.

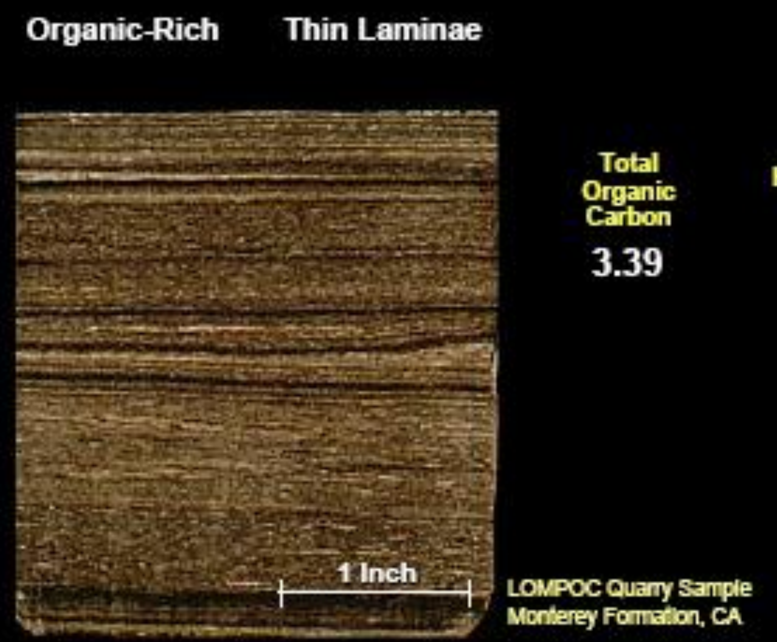
Increasing: Temperature + Pressure + Time

Preserved organic matter is *Transformed* into *kerogen* then to *hydrocarbons*

- Certain geologic environments favor the accumulation and preservation of organic matter
  - *large lakes and swamps*
  - *regions of coastal upwelling*
  - *tropical continental shelves*

Characters of source rocks

- *Fine-grained* (usually shale)
  Laminated: no bioturbation, no benthos
- *Sedimentation in deep water:* lack of oxygen, no water mixing
- *Deposited in Low-oxygen depositional environment:*, (C_{org}) does not become oxidized
- *High sedimentation rates* with high rates of organic material preservation



2. The Reservoir Rock

- Pools of oil are found in underground traps within host sedimentary rocks.
- The host sedimentary or reservoir rock is still porous enough for the oil to accumulate in spaces between the sediment grains.

- An outcrop of pebbly sandstone (at base of cliff) overlain by red sandstone.
- A few kilometers to the east these beds dip into the subsurface, and form part of the oil reservoir at the Wytch Farm Field, which is Britain's largest onshore oil field.

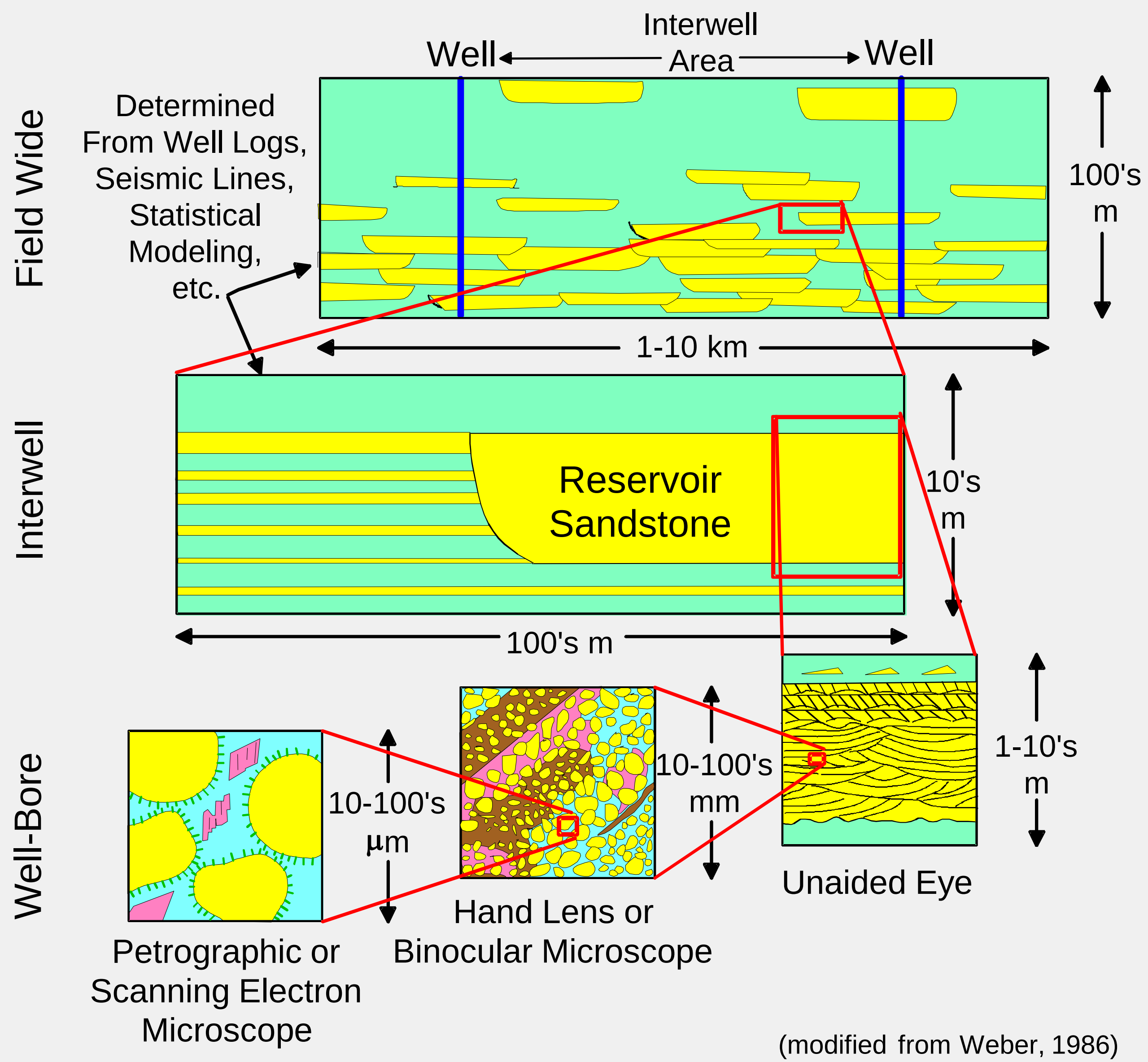
Note that

One of the main objectives of reservoir geology evaluation is to examine the impact of reservoir heterogeneities on reservoir behavior.

Reservoir Heterogeneity

- 1^{ST} Order: 1-10 km, large faults and sharp boundaries of facies belts, major sequence stratigraphic surfaces
- 2^{nd} Order: cm – 10's m, coarse-scale grain-size variations, etc.
- 3^{rd} Order: mm to m, fine-scale grain-size variations,
- 4^{th} Order: micron to mm, very fine-scale grain size variations, laminae, laminasets.

Scales of Geological Reservoir Heterogeneity



Types of Reservoir Rock

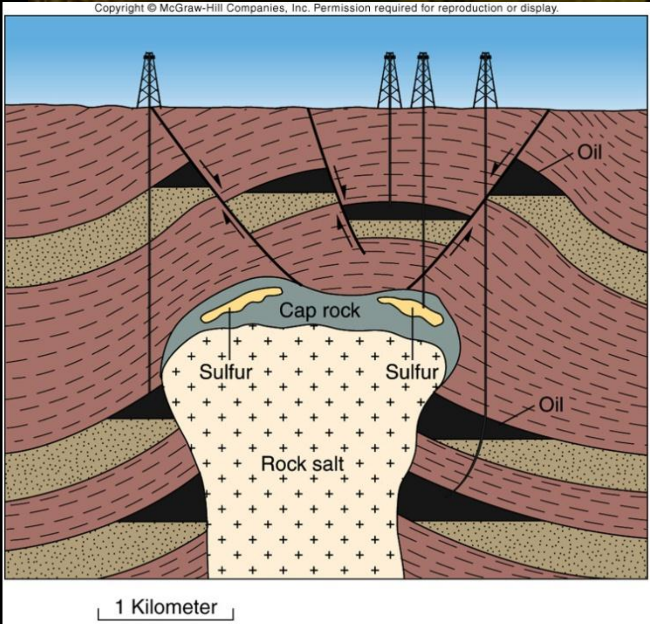
- Siliciclastic
- Carbonate
- Fractured

Sandstone

Limestone

3. The Seal

- Sealing is an important element in the play, it helps to prevent fluid from escaping
- Sealing rock must be relatively impermeable
- Typical cap rocks (seals) are: evaporites, chalks and shales
- Elastic cap rock (sealing) is better than plastic ones s it is not fractured easily



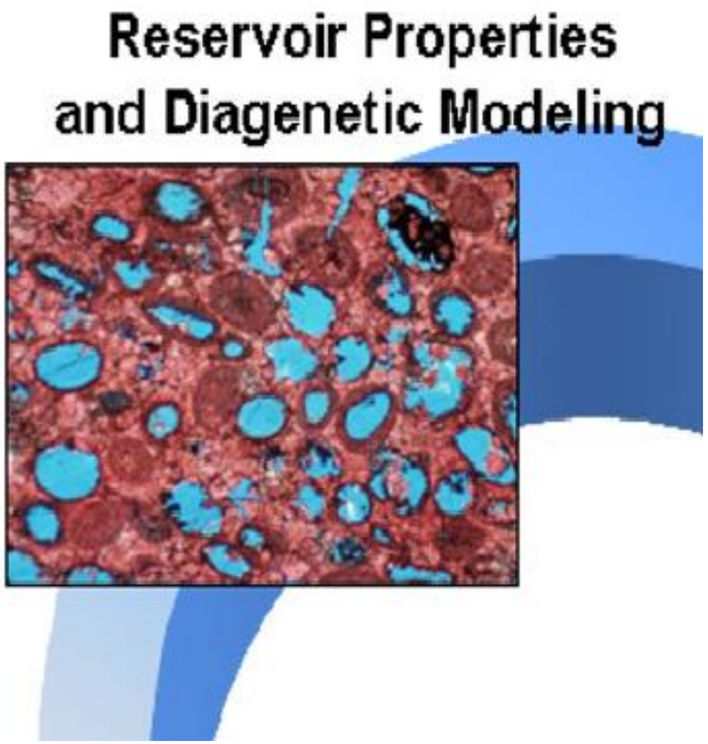
3. Final phase of development

drilling and production

3. Final phase of development drilling and production

A. Petrography

- Petrographic analysis of reservoir rocks provides essential information during exploration and production phases.

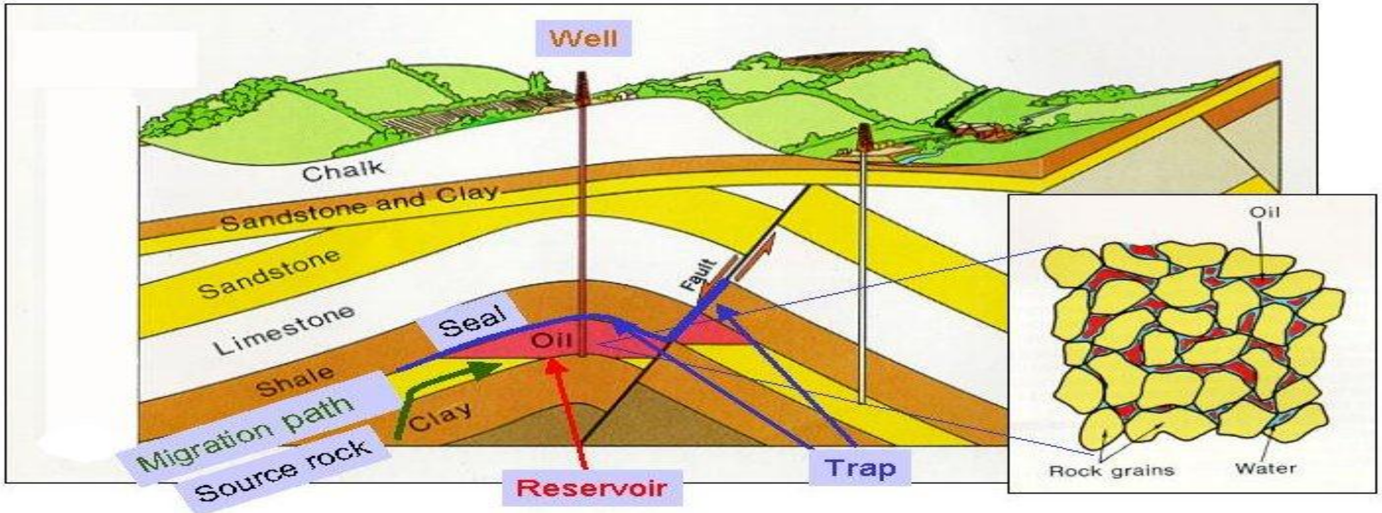


B. Diagenesis

- Diagenesis continuously alters sedimentary rocks and consequently their petrophysical properties .

C. Petrophysics

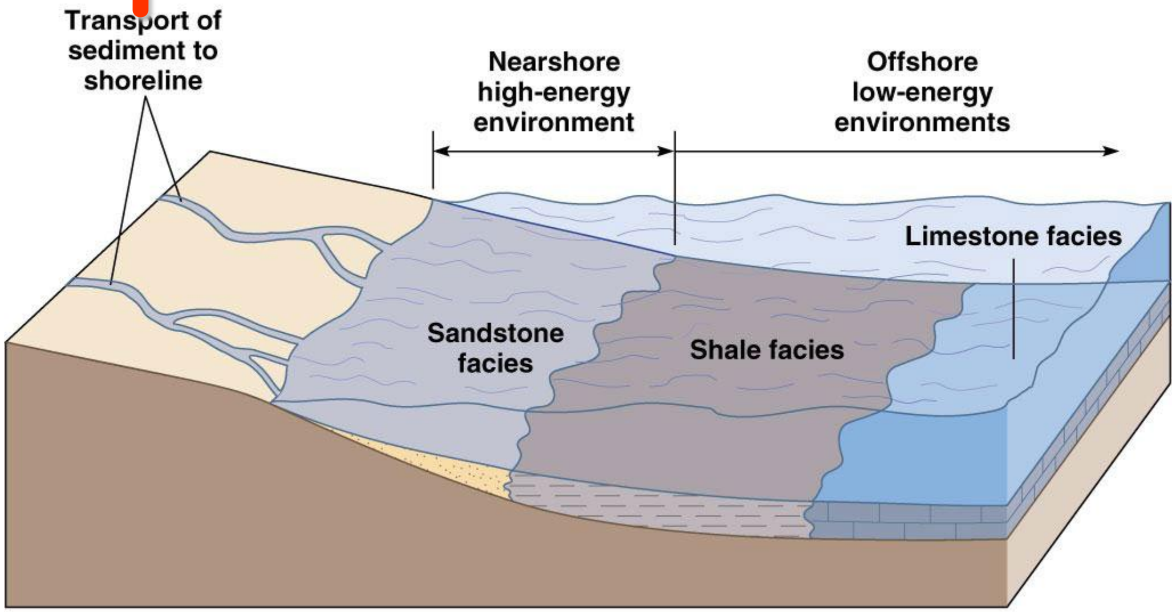
Drill_3.mpg



•Petrophysics is the study of the physical properties of the rocks. The assessment of the controlling parameters, such as porosity, pore structures and permeability in sediments and sedimentary rocks is essential in the evaluation of reservoir characteristics.

•Few reservoirs are petrophysically isotropic. Most oil fields show variations among their petrophysical characters. These variations are due either to primary depositional features or to secondary diagenetic changes.

D) Depositional Architecture

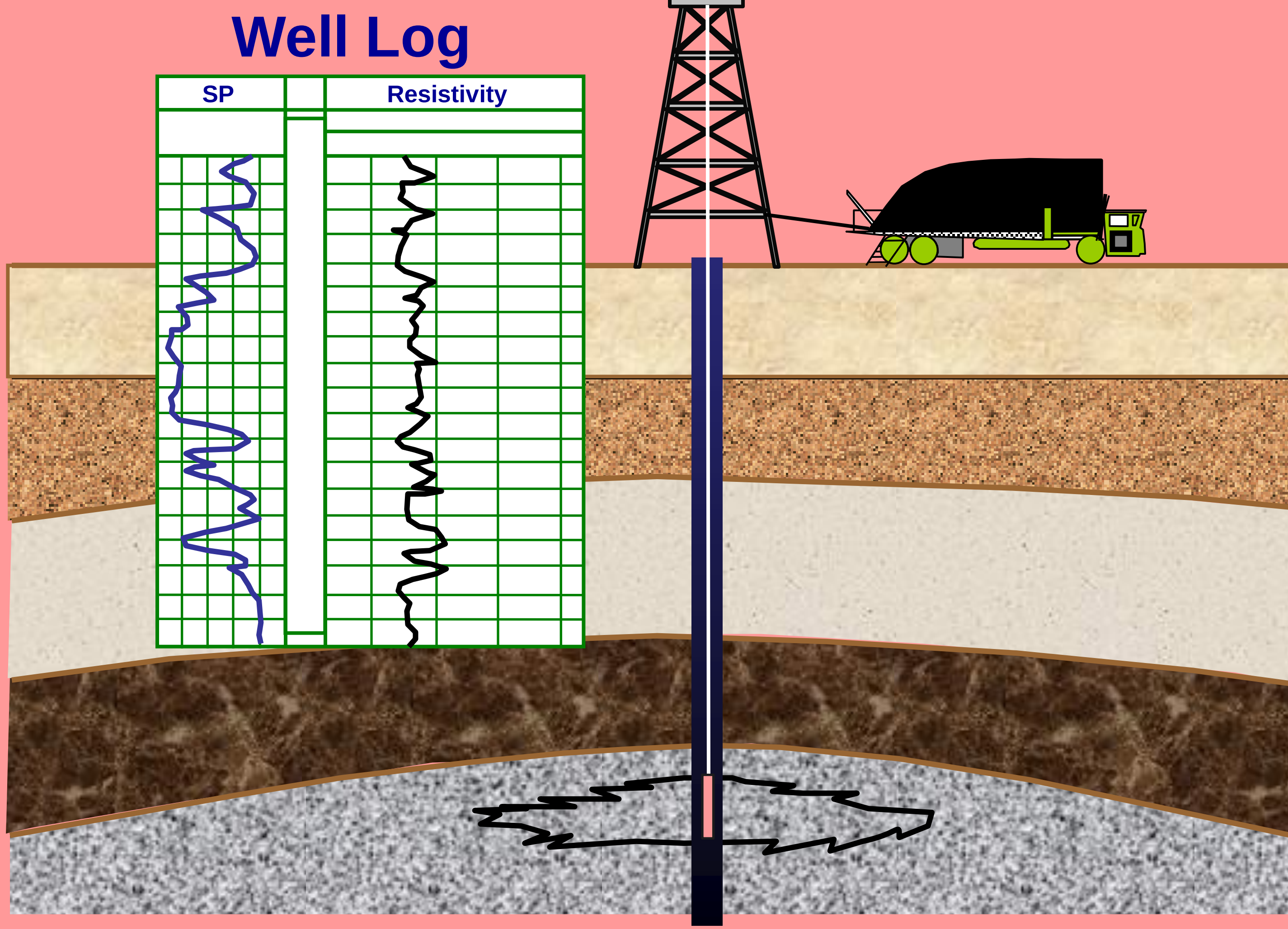


- Sedimentary depositional environments are inherently heterogeneous because of the superposition of sedimentary and diagenetic processes during successions of relative sea level changes.
- Understanding flow in reservoirs depends on knowledge of the architecture of sedimentary structure and lateral and vertical heterogeneity of facies in response to environmental impacts.

Available Data and their Uses

DATA	USES
•Cores •Cuttings •Thin sections	•Facies, dep. environment Paleocourrent directions •Mineralogy, lithology •Mineralogy, lithology
•Paleontology (micro, macro, traces), •Palynology	•Water depth, depositional environment, time line; paleocurrent direction, lithofacies
• Logs	•Paleocurrent directions, lithofacies •Lithology, Porosity,

Openhole Log Evaluation



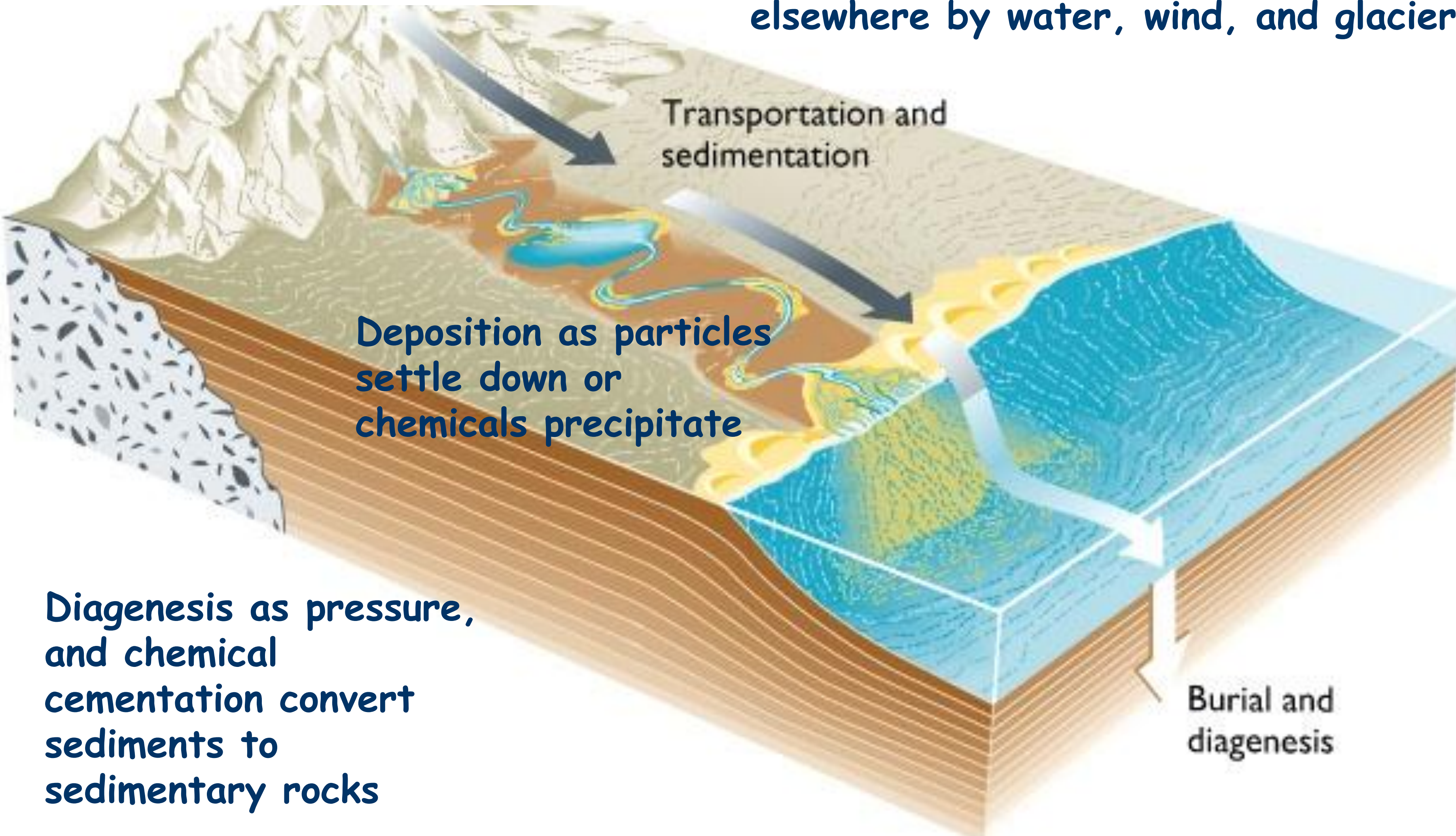
Before oil, how the oil container (reservoir) was formed?

Origin of Sedimentary Rocks

Sedimentary Stages in the Rock Cycle

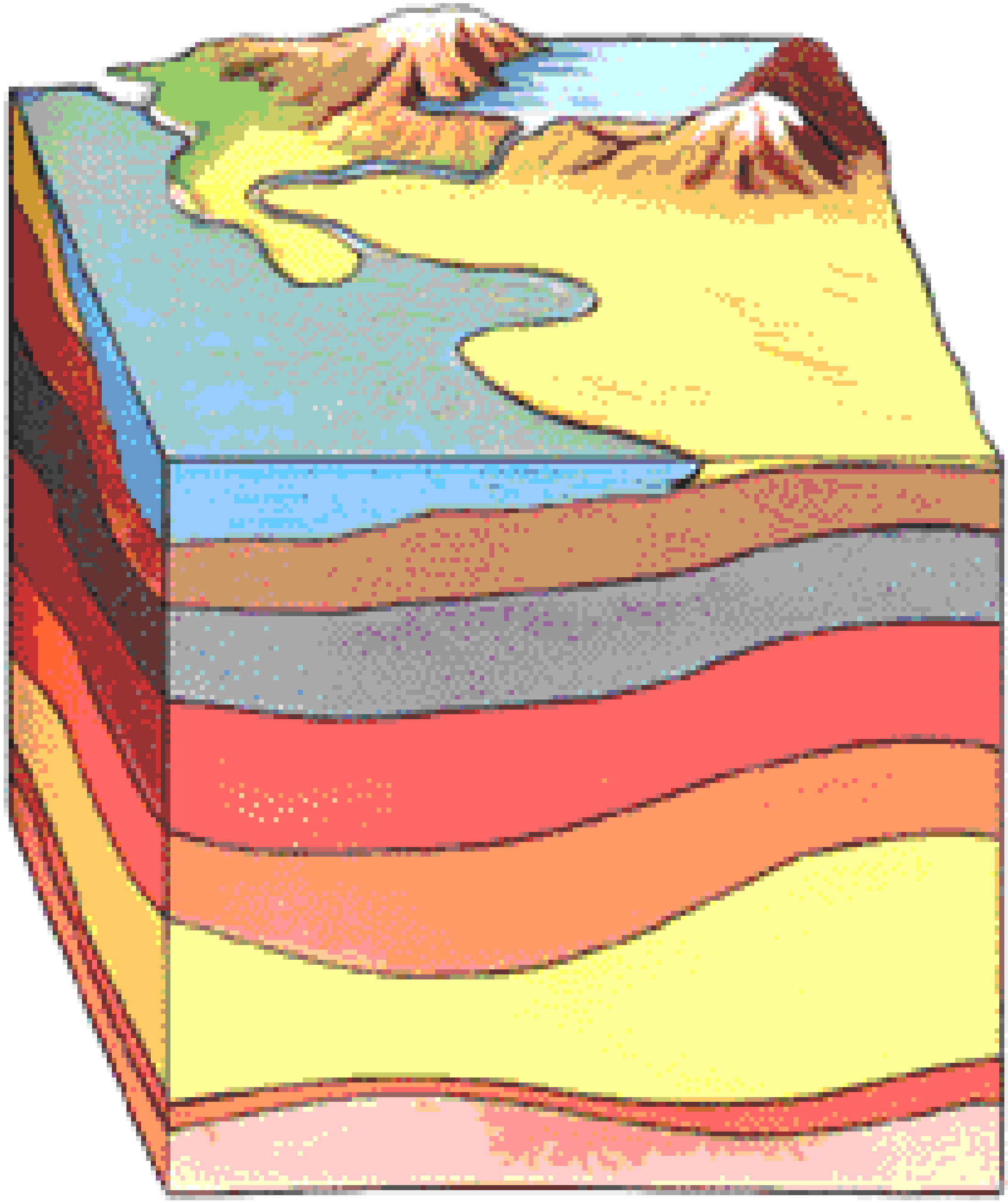
Weathering & Erosion breaks rocks down into smaller particles and produce sediments

Transportation removes sediment from its source area and carries it elsewhere by water, wind, and glaciers

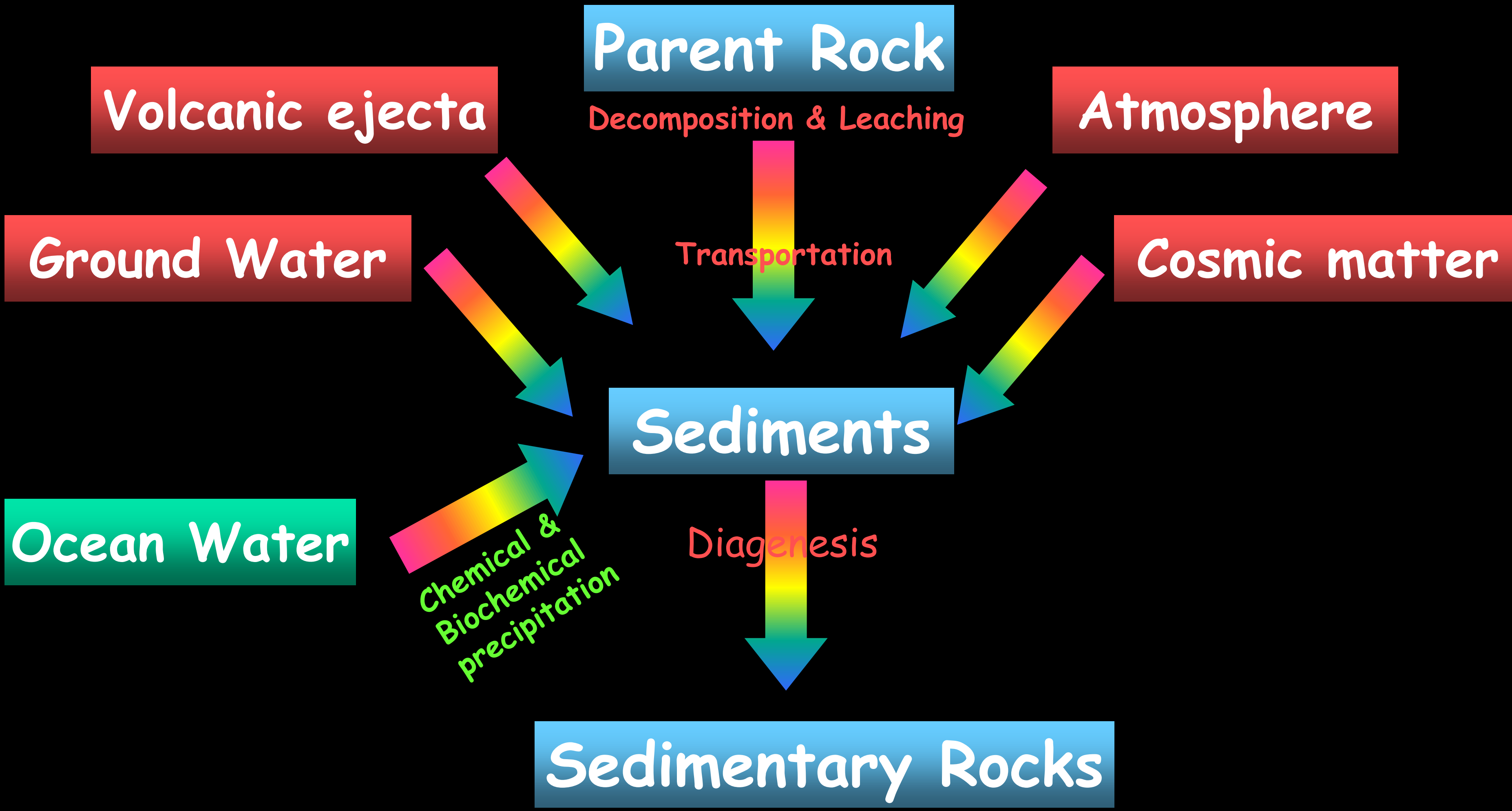


Deposition as particles settle down or chemicals precipitate

Diagenesis as pressure, and chemical cementation convert sediments to sedimentary rocks



Origin of Sedimentary Rocks



Source area (any preexisting rock)

- Chemical weathering
  Weathering products
  - Clay minerals
  - Ions and compound in solution
- Transportation
  - Precipitation from solution
  - Used by organisms
- Deposition (non-detrital sediments)
- Lithification
- Chemical & Biochemical sedimentary rocks
  (e.g. limestone)

- Physical weathering
  Weathering products
  - Gravel, sand, silt and clay-sized particles
- Transportation
- Deposition (detrital sediments)
- Lithification
- Detrital sedimentary rocks
  (e.g. sandstone)

So, It is now evident that

Sedimentary rocks are the product of

1. <u>the creation</u> of detritus and solutes derived from pre-existing rocks.
2. <u>transportation</u>,
3. <u>deposition</u>, and
4. <u>diagenesis</u>


What are the types of
Sedimentary Rocks?

Sedimentary rocks may be classified according to:

1. Genesis into:
- *Exogenetic sedimentary rocks* formed of components derived from outside the basin of accumulation
- *Endogenetic sedimentary rocks* formed of components formed within the basin of accumulation

2. Mode of Formation into:
- *Mechanical sedimentary rocks* formed by the fragmentation of pre-existing rocks where the resultant fragments are transported to the basin
- *Chemical sedimentary rocks* formed by direct chemical precipitation from fluids
- *Biochemical sedimentary rocks* formed chemically by the aid of organisms

3. Fabric Components into:
- *Clastics* composed of rock pieces that are derived from pre-existing rocks
- *Non clastics* composed of grains formed in situ or crystals nucleated from the solution

Rock Identification is based on:

- *Composition*

  What minerals make up the rock?

- *Texture*

  What is the shape, size and orientation of the mineral grains that make up the rock?

  Major Difference: Crystalline vs. Clastic

Sedimentary rocks may be classified according to:

Fabric Components into:

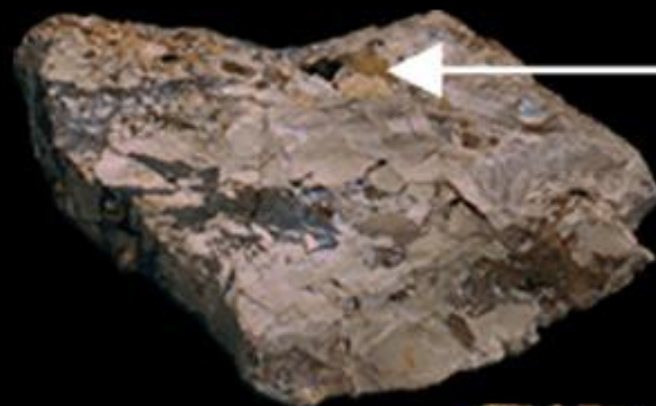
1. <u>*Clastics*</u> composed of rock pieces that are derived from pre-existing rocks. These pieces are usually formed by the fragmentation of pre-existing rocks where the resultant fragments are transported to the basin

2. <u>*Non clastics*</u> composed of grains formed in situ or crystals nucleated from the solution either by:
    - <u>*Chemical precipitation*</u> by direct chemical precipitation from fluids
    - <u>*Biochemical precipitation*</u> by the aid of organisms

Types of Sedimentary Rocks

•Composed of chemical minerals formed either by direct chemical precipitation or under the influence of biological processes

Non clastics



Calcite and Dolomite

Limestone

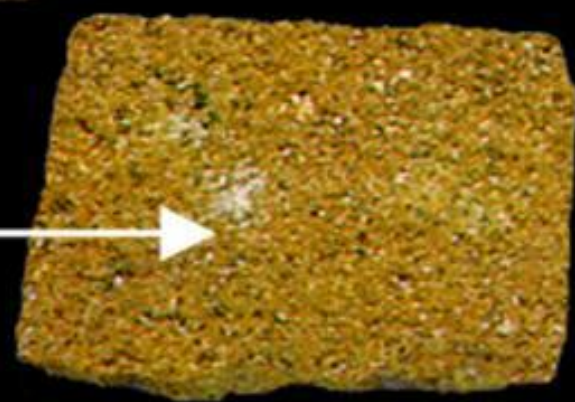
•Consist Primarily of Silicate Minerals

•Are Classified on the Basis of:

- Grain Size
- Mineral Composition

Quartz and Clay Minerals

Sandstone



Clastics

Clastic Sediments

Clastic sediments are made up of pieces of preexisting rock (clastic particles; detritus) & minerals (Quartz, Feldspars, Micas) derived from physically transported rock fragments produced by weathering.

So they may contain:

- *retained minerals (e.g. quartz)*
- *unaltered pieces of pre-existing rocks*
- *partially weathered particles,*
- *new particles produced by weathering (clay minerals).*

- These sediments accumulate rapidly (10x more than chemical and biochemical sediments).

Types of Clastic sediments include

1. Siliciclastics *are those composed of (non-volcanic) particles of all sizes, clay to boulders* . They are the most important among other clastic rocks related to their abundance and distribution.
2. Volcaniclastics *are those composed of eruptive volcanic rock particles*
3. Cosmoclastics *are those composed of particles derived from cosmic sources i.e. from the outer space*

Types of Siliciclastic (detrital) Sedimentary Rocks

Largely based on the size of the particles,

- *Conglomerate* (poorly sorted/rounded)
- *Breccia* (poorly sort/angular)
- *Sandstone* (quartz arenite , arkose, greywacke)
- *Mudstone*
- *Siltstone*
- *Shale* - most common rock on the continents

Detrital Rock Names
(Based Primarily on Grain Size)

Gravel -Sized: Conglomerate

Sand Sized: Sandstone

Siltstone

Shale

Mud-Sized: Mudstone

Coarse Clastic Particles

Conglomerate

Medium Clastic Particles (sands)

Quartz sand

Quartz sand

Sandstone


Shale

Non Clastic Rocks

- Rocks formed by the precipitation of minerals from solution from ions or molecules derived from dissolved weathering products
- Precipitation occurs by either organic or inorganic processes

Types of Non Clastic Sedimentary Rocks

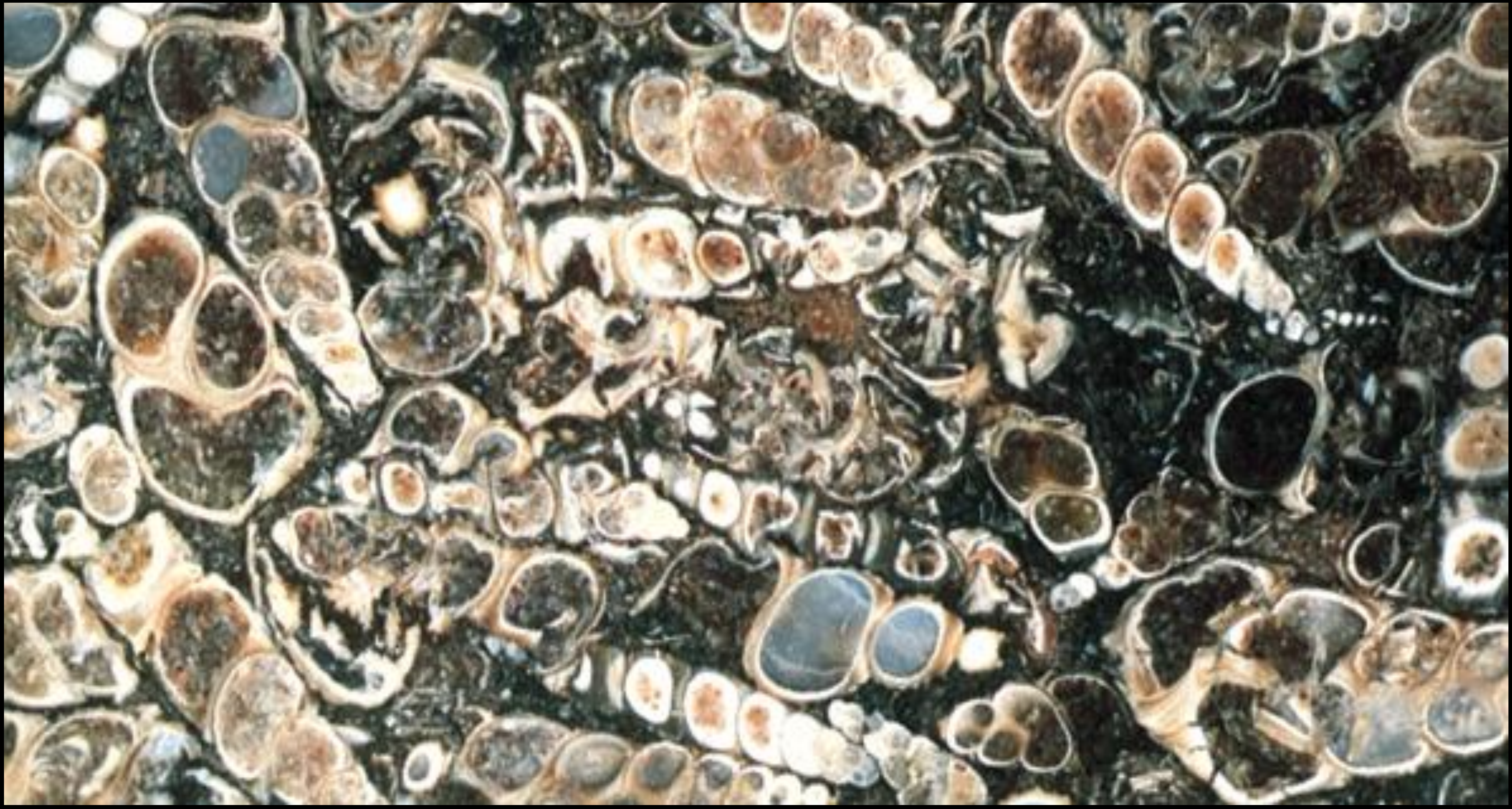
Limestone	$CaCO_3$
Chert	SiO_2
Rock Salt	$NaCl$, KCl
Gypsum	$CaSO_4 \cdot 2H_2O$
Coal	C
Phosphate	$Ca_5(PO_4)_3F$

Limestone

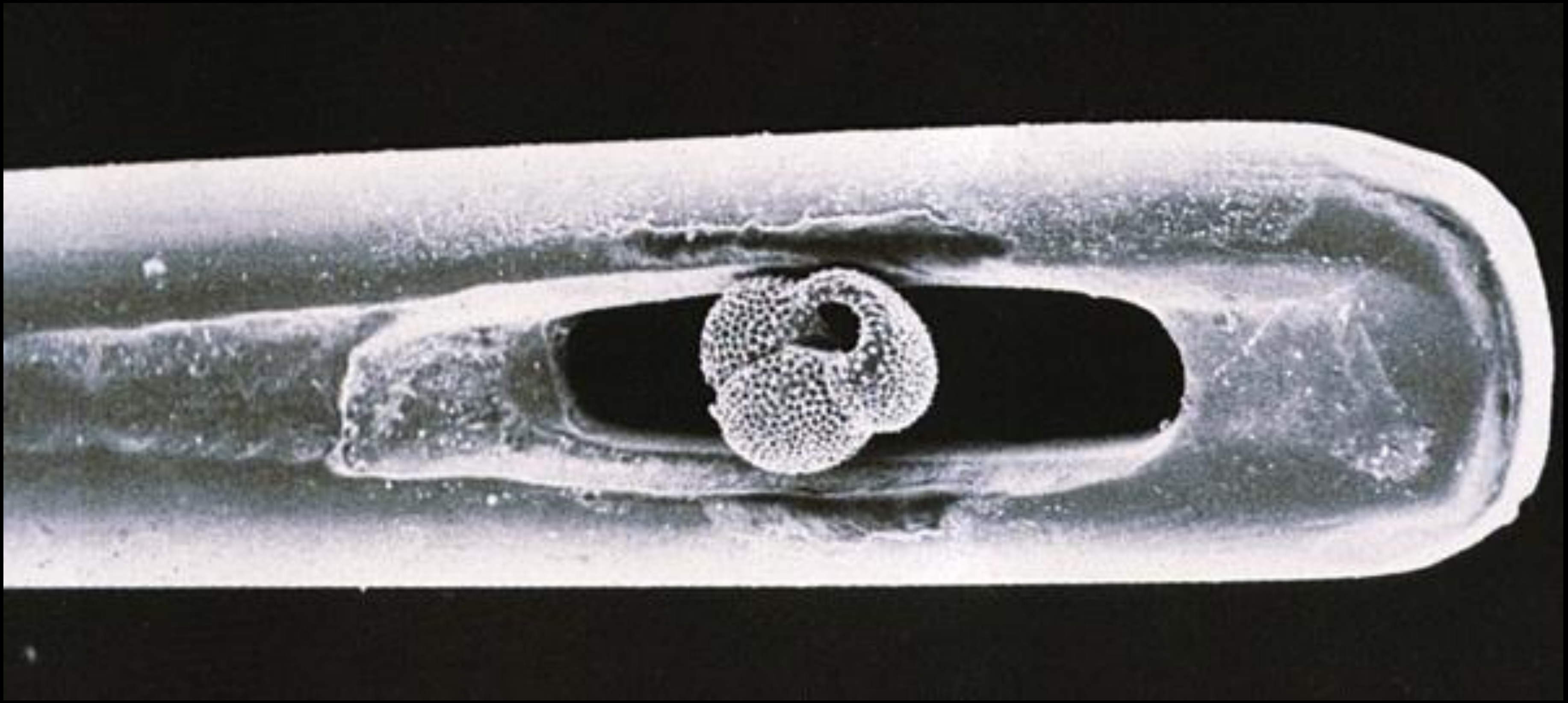
Halite

Chert

Fossiliferous Limestone



Foraminifer in the Eye of a Needle



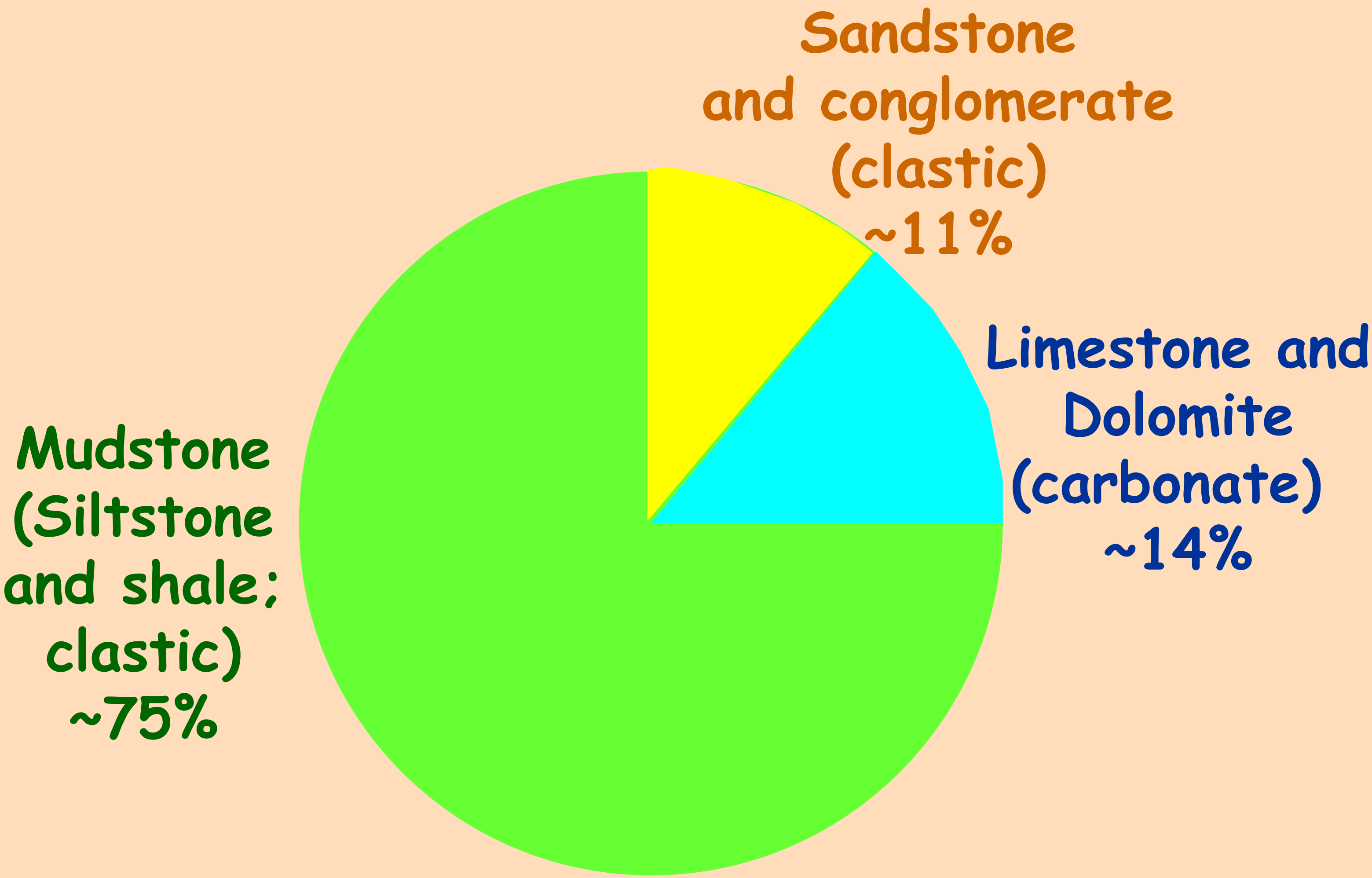

Reefal Limestone


Reefal
Carbonate
Deposits

Coal

Sedimentary Rock Types

Relative Abundances



What the course is about?

1. **Introduction and Definitions**
2. **Factors controlling the production of clastic sediments and sedimentary rocks**
   (Weathering, Erosion, Transportation, Deposition and depositional environments, Diagenesis)
3. **Clastic Reservoir Properties**
   - *Sedimentary Structures*
   - *The impact of clastic textures and fabrics on reservoir characterization*
   - *Petrographic types of clastic reservoir rocks*
   - *How clastic reservoir properties are affected by diagenesis*
4. **Clastic Reservoir Development and Morphology**
   - *Clastic facies and facies analysis*
   - *Clastic depositional environments*
   - *The concept of sequence stratigraphy and how it is used in clastic reservoir characterization*